NORTH ATLANTIC TREATY ORGANISATION

RESEARCH AND TECHNOLOGY ORGANISATION

AC/323(SAS-054)TP/51

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RTO TECHNICAL REPORT **TR-SAS-054**

Methods and Models for Life Cycle Costing

(Méthodes et modèles d'évaluation du coût de possession)

Final Report of Task Group SAS-054.

Published June 2007

Distribution and Availability on Back Cover

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 2007**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Methods and Models for Life Cycle Costing (Méthodes et modèles d'évaluation du coût de possession)**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Research and Technology Organisation North Atlantic Treaty Organisation BP 25, F-92201 Neuilly-sur-Seine Cedex, France**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**		
13. SUPPLEMENTARY NOTES **The original document contains color images.**		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**226**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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Methods and Models for Life Cycle Costing

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Final Report of Task Group SAS-054.

The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote co-operative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective co-ordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also co-ordinates RTO's co-operation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of co-operation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier co-operation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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Published June 2007

ISBN 978-92-837-0072-2

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List of Acronyms

AACP	Allied Acquisition Practices Publications
AACP-1	Guidance Manual for Cooperative Programme Arrangements
AAP	Allied Administrative Publication
AAP-20	Handbook on the Phased Armaments Planning System
AAP-48	Handbook to NATO System Life Cycle Management Volume 1 & 2 (Initial Draft), February 2006
ABC	Activity Based Cost
AC/327	NATO Life Cycle Management Group (LCMG)
ACAT	Acquisition Category
ACWP	Actual Cost of Work Performed
AGS	Alliance Ground Surveillance System
AHP	Analytic Hierarchy Process
ALP-10	Guidance on Integrated Logistic Support (ILS) for Multinational Equipment Projects
ANEP-41	NATO standard for shipbuilding Work Breakdown Structures
AoA	Analysis of Alternatives
APB	Acquisition Programme Baseline
ARM	Availability, Reliability and Maintainability
AWACS	Airborne Warning and Control System
BCWS	Budgeted Cost of Work Scheduled
BWA	German Defence Materiel Administration
CAIG	Cost Analysis Improvement Group
CALS	Continuous Acquisition and Life Cycle Support
CARD	Cost Analysis Requirements Description
CBA	Cost Benefit Analysis
CBS	Cost Breakdown Structure
CCDR	Contractor Cost Data Reporting
CDB	Cost Data Base
CDIP	Cooperation on Defence Implementations of PLCS
CER	Cost Estimating Relationship
CM(62)18	NATO Council Resolution C-M(62)18 on Regulations for NATO Production and Logistics Organizations
CNAD	Conference of National Armaments Directors
COEIA	Combined of Operational Effectiveness and Investment
CONOPS	Concept of Operations
COTS	Commercial Off-The-Shelf [models]
CPI(h)	Cost Performance Index
CSDR plan	Cost and Software Date Reporting Plan
CV	Cost Variance
DCARC	US Defense Cost and Resource Center
DEX	Data EXchange Sets

DGA	French Defence Materiel Administration
DGAT	Direzione Generale Degli Armamenti Terrestri (Italy)
DoD	US Department of Defense
DOE	US Department of Energy
DOTMLPF Solutions	Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities Solutions (US DoD)
EAC	1) Estimate at Completion or Estimated Cost of Contract at Completion 2) Equivalent Annual Cost
EDCAM	Educational Cost Effectiveness Analysis Model
ERP	Enterprise Resource Planning
EVM	Earned Value Management
FAA	Federal Aviation Administration (US)
FACET	Family of Advanced Cost Estimating Tools, HVR Consulting Services Ltd.
FFI	Norwegian Defence Research Establishment
FMV	Swedish Defence Materiel Administration
FOI	Swedish Defence Research Agency
FOM	Figure of Merit
FREMM	Frégates Européennes Multi-Missions
FWA	Factor Weighting Analysis
FY	Fiscal Year
FYDP	Future Years Defence Programme
GCBS	Generic Life Cycle Cost Breakdown Structure
GFX	Government Funded Equipment / support
GSE	Government Supplied Equipment
GWOT	Global War on Terrorism
i.a.w.	in accordance with
IH	In-house
ILS	Integrated Logistic Support
IPO	International Programme Office
IPT	Integrated Product Team
IPTL	Integrated Project Team Leader
ISO	International Standards Organisation
ISO 10303-239	Industrial automation systems and integration – Product data representation and exchange – Part 239: Application protocol: Product life cycle support
ISO 15288	ISO standard (published in October 2002) to deal with system life-cycle processes; hardware, software and human interfaces
ISP	Integrated Support Plan
ITT	Invitation to Tender
JSF	Joint Strike Fighter
KSLOC	Thousands of Sources Lines Of Code

LCC	Life Cycle Cost
LCCA	Life Cycle Cost Analysis
LCMG	Life Cycle Management Group (AC/327)
LCMP	Life Cycle Management Plan
LOC	Life Operation Cost
LORA	Level of Repair Analysis
LRU	Line Replaceable Unit
LSA	Logistic Support Analysis
LSAR	Logistic Support Analysis Record
LSC	Life Support Costs
MACE	Multi Attribute Choice Elucidation
Maint & Mgmt	Maintenance and Management
MANPRINT Plan	Manpower and Personnel Integration Plan
MCDA	Multi Criteria Decision Analysis
MDAL	Master Data and Assumptions List (UK)
MDAP	Major Defence Acquisition Programme
MIL	Generic Top Level Domain Name for U.S. military
MND	Mission Need Document
MoD	Ministry of Defence (UK)
MOEs	Measures of Effectiveness
MOPs	Measures of Performance
MoU	Memorandum of Understanding
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
MWT	Mean Waiting Time
NADDO	NATO Design and Development Objective
NADI	National Disengagement Intention
NAMSA	NATO Maintenance and Supply Agency
NAPO	NATO Production Objective
NATO	North Atlantic Treaty Organisation
NC3A	NATO Command, Control and Consultation Agency
NC3O	NATO Consultation, Command and Control Organisation
NCDM	NATO CALS Data Model
NH-90	Twin engine, 10.6 ton multi-role helicopter, developed to meet naval and tactical transport helicopter
NHSP	Nordic Standard Helicopter Programme
NIAG	NATO Industrial Advisory Group
NISEG	NATO In-Service Goals
NPDM	NATO Product Data Model
NPSC	NATO Project Steering Committee
NPV	Net Present Value
NSHP	Nordic Standard Helicopter Programme
NSR	NATO Staff Requirement
NST	NATO Staff Target

O&S	Operation and Support
OA	Operational Analysis
OASIS	Organization for the Advancement of Structured Information Standards
OCCAR	Organisation Conjoint de Coopération en matière d'Armement
ONST	Outline NATO Staff Target
OPTEMPO	Methodology to prepare budget requests that accurately reflect Operations and Maintenance requirements
OSD	Office of the Secretary of Defense
PAPS	Phased Armaments Programming System
PEO	Programme Executive Officer
PERT	Programme Evaluation and Review Technique
PESTEL analysis / techniques	Political, Economic, Social, Technological, Environmental and Legal analysis / techniques
PfP	Partnership for Peace
PHST	Packaging, Handling, Storage and Transportation
PLCC	Programme Life Cycle Cost
PLCS	Product Life Cycle Support
PM	Project Manager
PMB	Performance Measurement Baseline
PPP	Purchasing Power Parities
PV	Present Value
QDR	Quadrennial Defense Review (US)
R&D	Research & Development
R&M	Reliability and Maintainability
RDL	Reference Data Libraries
RDT&E	Research, Development, Test, and Evaluation
RFI	Request for Information
RFP	Request for Proposal
RFQ	Request for Quotation
RTA	Research and Technology Agency
RTG	Research Task Group
RTO	Research and Technology Organisation
SAS	Studies, Analysis and Simulation Panel / Working Group
SAS ET-AH	Exploratory Team on Methods and Models for Life Cycle Costing
SAS-028	Cost Structure and Life Cycle Costs (LCC) for Military Systems
SAS-054	Methods and Models for Life Cycle Costing
SAS-057	Information Operations In Smaller Scale Contingencies – Analysis and Capability Requirements
SAS-063	Benchmarking Studies and Capability Costing
SCAF	Society of Cost Analysis and Forecasting
SCEA	Society of Cost Estimating and Analysis
SE	Synthetic Environment
SLC	System Life Cycle

SLCM	System Life Cycle Management
SLOC	Source Lines Of Code
SME	Subject Matter Experts
SOI	System Of Interest
SPI(h)	Schedule Performance Index
SRDR	Software Sources Data Report
STANAG	NATO Standardization Agreement
STANAG 4661	ISO 10303-239 standard for exchange of life cycle data, put forward by NATO to be adopted as STANAG 4661
STEP	Standard of Exchange for Product Model Data
SV	Schedule Variance
T1	First Unit Cost
TAP	Technical Activity Proposal
TAT	Turnaround Time
TLCC	Total Life Cycle Cost
TNO	Contract Research Organisation in The Netherlands
TOA	Total Obligation Authority
TOC	Total Ownership Cost
TOR	Terms of Reference
TR	Technical Report
UAV	Unmanned Aerial Vehicle
UPC	Unit Production Cost
VAMOSC	Visibility And Management of Operation and Support Costs
VAT	Value-Added Tax
VSW	Very Shallow Water
WBS	Work Breakdown Structure
WLC	Whole Life Cost
WT_A	Waiting Time
WT_{LRU}	Waiting Time Line Replacable Unit

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Acknowledgements

We would like to thank all the participation nations and, in particular, those members of the programme committee for their contribution which will be of benefit to all NATO and PfP nations.

We would also like to recognise the contribution of Mr. Marcel Smit for his Chairmanship of the study and to Mr. Arthur Griffiths who acted as Secretary and Editor of the report.

Methods and Models for Life Cycle Costing

(RTO-TR-SAS-054)

Executive Summary

The core objectives of the SAS-054 Task Group were to understand NATO and PfP Nations' methods and models and to promulgate best practice in life cycle costing that can be adopted throughout the various NATO Phased Armaments Programming System (PAPS) phases. This is particularly important where decisions are made when the amount of supporting information to provide robust life cycle costs are sparse.

There are many methods and models available to conduct life cycle cost analysis and it was important to understand the applicability and boundaries of each method and model in order to use them appropriately.

The report contains a review of cost forecasting methods and models together with examples to provide a comprehensive guideline in the application of life cycle costing and particularly in its use within multi-national programmes.

It is accepted that a life cycle cost estimate of weapon systems is inherently uncertain and will contain risk. The treatment of uncertainty and risk within the context of developing the life cycle cost estimate is also explained within the report.

The report therefore provides the reader with a comprehensive view on the application and use of life cycle costing from an early conceptual phase in the product life cycle through to disposal. It provides illustrations on the types of life cycle cost studies that can be conducted and examples to demonstrate the benefits. The report concludes with a number of recommendations to improve the use and understanding of life cycle costing in the decision making process.

Méthodes et modèles d’évaluation du coût de possession

(RTO-TR-SAS-054)

Synthèse

Les objectifs principaux du Groupe de Travail SAS-054 furent de comprendre les méthodes et modèles de l’OTAN et des nations du Partenariat pour la Paix (PfP), et de faire valoir les bonnes pratiques en matière d’évaluation du coût de possession, qui pourraient être adoptées dans les différentes phases PAPS (système de programmation échelonnée des armements) de l’OTAN. Ceci est particulièrement important quand des décisions sont prises lorsque la somme des informations permettant d’évaluer le coût de possession est faible.

Il existe de nombreuses méthodes et modèles disponibles pour ce faire ; et il est important de comprendre l’applicabilité et les limites de chaque méthode ou modèle pour les utiliser à bon escient.

Ce rapport examine des méthodes et modèles de prédiction de coûts, ainsi que des exemples servant de guide pour l’évaluation du coût de possession, et plus particulièrement dans le cadre d’utilisations multinationales.

Il est généralement admis que l’estimation du coût de possession d’un système d’arme est de fait incertaine et qu’elle comporte des risques. Le traitement de cette incertitude et de ce risque dans le contexte du développement de l’estimation du coût de possession est aussi expliqué dans ce rapport.

Ce rapport fournit donc au lecteur une vue complète sur l’application et l’utilisation de l’analyse du coût de possession depuis une phase conceptuelle avancée dans le cycle de vie d’un système d’arme, jusqu’à son retrait. Il illustre les études sur les analyses des coûts de possession qui pourraient être menées et des exemples démontrant ses avantages. Ce rapport conclut par un certain nombre de recommandations pour améliorer l’utilisation et la compréhension de l’analyse du coût de possession dans la prise de décision.

OVERVIEW

The results of life cycle costing must, whatever the phase of the programme, contribute to the process by which managers can make the best decisions on options presented to them. These options can include evaluation of future expenditure, comparison between alternative solutions, management of existing budgets, options for procurement and evaluation of cost reduction opportunities. Life cycle costing is also used for affordability assessment and determining the cost drivers associated with the Key Performance Indicators or Key User Requirements. There are many methods and models available to conduct life cycle cost estimates. It is important to understand the applicability and boundaries of each method and model in order to use them appropriately.

The core objectives of the SAS-054 Task Group were to understand NATO and PfP Nations' methods and models and to promulgate best practice within the NATO Phased Armaments Programming System (PAPS) phases. In order to meet this aspiration the following objectives were defined in the Task Group terms of reference.

O.1 REVIEW OF COST FORECASTING METHODS

The report has captured all the key estimating methods and provided examples to demonstrate their applicability. For consistency, both the methods and models have been categorised as Optimisation, Simulation, Estimation and Decision Support. The findings confirmed that almost all nations used a similar process to develop life cycle cost estimates; that the quality of the available data nearly always determined the method to be employed; and, in addition, that the type of study also influenced the process and the selection of the appropriate method.

O.2 REVIEW OF COST FORECASTING MODELS

In developing life cycle cost estimates all the nations have in-house developed models that are based on a defined Cost Breakdown Structure. Data for these models is estimated either by empiric methods or parametric formulae (for completeness, sometimes both techniques are employed). The findings confirmed that there were many life cycle cost models in use and these are identified within the report. Generally speaking, the use of more than one model to produce a life cycle cost estimate is considered good practice. This would provide verification of the life cycle cost estimate. However, the use of multiple methods and models should always be balanced with the knowledge and understanding of how the estimate will be used. It is important to ensure that the life cycle costing activities are conducted in a cost-effective manner and balanced with what is realistically achievable at a specific stage in the programme. It is also important to ensure that every model used for acquisition and life cycle costing is subject to calibration, verification and validation. This will build confidence that the cost model is fit for purpose.

O.3 GUIDELINES FOR THE COLLECTION AND UNDERSTANDING OF COST RELATED DATA FOR NATIONAL AND MULTI-NATIONAL PROGRAMMES

In terms of time, effort, and resources consumed, collection of data is a major part of a life cycle cost study. Life cycle costing is a data driven process, as the amount, quality and other characteristics of the available data often define what methods and models can be applied, what analyses can be performed, and therefore determine the usefulness of the results that can be achieved. Unfortunately, because uncertainty, risks, and opportunities decrease as the life cycle progresses, the need for knowledge is greatest at the earliest stages. This means that more time and resources should be allocated to the data

collection effort during the earlier stages of the life cycle in order to develop an acceptable and auditable life cycle cost estimate.

O.4 TREATMENT OF UNCERTAINTY AND RISK

Life cycle cost estimates of defence programmes are inherently uncertain and risky. Estimates are often made when information and data is sparse. Estimates, in turn, are based on historical samples of data that are almost always messy, of limited size, and difficult and costly to obtain. And no matter what estimation tool or method is used, historical observations never perfectly fit a smooth line or surface, but instead fall above and below an estimated value. To complicate matters, the weapon system under study is often of sketchy design.

For all of these reasons, a life cycle cost estimate, when expressed as a single number, is merely one outcome or observation in a probability distribution of costs. To better support the decision making process it is recommended that three point estimating is always undertaken. This study has captured a wide variety of methods and models available for conducting risk and uncertainty analysis of life cycle cost estimates of weapons systems. Each, if used properly, can give scientifically sound results and provide a better yardstick for an accurate life cycle cost estimate.

O.5 GUIDELINE FOR MULTI-NATIONAL PROGRAMMES

Multi-national programmes involve at least two nations who have agreed upon the main principles of co-operation in a Memorandum of Understanding, or an equivalent arrangement, for one or several phases of the entire lifetime of that programme. It has been found that the life cycle cost studies for multi-national programmes follow the same principles as national life cycle cost requirements. However, there are some specifics that have to be taken into account in terms of organisation, currency issues, studies, model(s) and presentation of the life cycle cost results.

O.6 REVIEW AND POSSIBLE ENHANCEMENT OF THE NATO GENERIC COST BREAKDOWN STRUCTURE

The NATO generic cost breakdown structure developed by SAS-028 has been reviewed by participating nations and organisations. Within the report it is recommended that some changes to the NATO generic cost breakdown structure be made based on recent OCCAR experience in implementing it on multi-national programmes.

O.7 AWARENESS OF NEW DEVELOPMENTS IN METHODS AND MODELS

A number of new developments have been identified that will impact on life cycle costing and analysis activities. Some appear to stem from changes in the types of studies being conducted (e.g. capability estimating, system of systems estimating, etc.). This will not change the way life cycle costing is conducted, but it has changed the interpretation of the costing boundary of the estimates.

In addition, to more effectively manage scarce defence resources, several NATO and PfP nations are initiating efforts to analyse the costs, capabilities, and risks within an entire portfolio of assets in a joint war-fighting environment. Viewing capabilities across the entire portfolio of assets enables the decision makers to make better informed choices about how to reallocate resources with the ultimate goal of delivering needed capabilities to the joint force more rapidly and efficiently. Capability portfolios are intended to serve as a basis for strategic level trade studies by senior decision makers.

It is recommended that further studies be conducted to better understand the life cycle costing requirements and benefits to the decision making process that these new developments may bring.

O.8 CONCLUSION

The report provides details on the findings of the Task Group into the methods and models being used for life cycle costing. In addition, it has examined data collection, the measurement of risk and uncertainty, new developments and other related life cycle cost issues. The report concludes with a number of recommendations to improve the use and understanding of life cycle costing in the decision making process. The most important recommendation is to implement this work as NATO policy.

O.9 KEY RECOMMENDATIONS

The following key recommendations are made with regard to the development and improvement in life cycle costing for multi-national programmes.

O.9.1 Life Cycle Costing Methods

1) **Life cycle cost estimates should be fully documented (Sub-section 2.3.2)**

   - A cost analyst should be able to re-create the complete estimate working from the documentation alone.
   - All assumptions and data related to the study should be captured in an MDAL or CARD or similar document.
   - Assumptions recorded in an assumptions list such as the MDAL or CARD should be questioned by an independent technical team.

2) **All life cycle cost estimates should be prepared by suitably experienced personnel (Sub-section 5.2.3.1)**

   - Decisions such as budget setting and options analysis studies are often conducted when data to support cost forecasting and life cycle costing is very sparse. It is therefore essential that experienced personnel are used to conduct the life cycle cost estimates to support the decision process at these key stages.

3) **The life cycle cost analysis should include an affordability analysis (Sub-section 2.9)**

   - Affordability plays an important part in programme decisions throughout the life cycle. Even before a programme is formally approved for initiation, affordability plays a key role in the identification of capability needs. This aspect is part of the process which balances cost versus performance and in establishing key performance parameters. Although this is not common practice in all nations the assessment of affordability is one that we recommend should be conducted by all nations.

4) **Life cycle cost estimates, where possible, should use two independent methods for each cost breakdown structure element (Sub-section 4.4)**

   - The use of two independent methods to develop the life cycle cost estimates will improve the confidence in the results and help to validate the outputs. It is accepted that this may be tempered by the constraints imposed by a financial threshold (see Sub-section 2.6) or by a simple consideration of what the estimate will be used for (e.g. rough cost for initial views or detailed costs for decision making).

O.9.2 Life Cycle Cost Models

5) All life cycle cost models should be validated (Sub-section 5.5)

- It is essential that all life cycle cost models implemented through spreadsheets or more advanced programming techniques be validated by using recognised testing processes. This will increase confidence that the model is fit for purpose and that the input data and results can be assessed through a clear audit trail and mathematical reasoning of any cost estimating relationships.

O.9.3 Data for Life Cycle Costing

6) Investments should be made to increase the accuracy, visibility, and availability of cost, programmatic, technical, and performance data within the NATO/PfP cost analysis community (Chapter 6).

- Data collection forms a large part of the life cycle costing activity and significant effort is expended to gather and analyse the data so that it is suitable for use in life cycle cost analysis studies. Improvements in data exchange standards or even the development of a NATO costing database would:
  - Improve the quality of the life cycle cost estimate;
  - Reduce the effort needed to conduct the life cycle cost estimate; and
  - Reduce the time schedule to conduct the life cycle cost estimate.

O.9.4 Multi-National Programmes

7) For multi-national programmes the participating nations should agree on a common LCC framework (Sub-section 2.10.6)

- The life cycle cost studies for multi-national programmes follow the same principles as those required by a national study. However, there are some specifics that must be taken into account in terms of organisation, models and the presentation of results. It is essential that all parties in a multi-national programme agree on a common life cycle cost framework. This framework is determined by the costing boundary and the tools that will be employed to populate the framework. A common framework will provide consistency, comprehensiveness, traceability and audit. All are essential to achieve life cycle cost estimates in a timely and responsive manner.

O.9.5 NATO Generic Cost Breakdown Structure

8) Enhancements to the GCBS (generic cost breakdown structure) to improve its use (Chapter 10)

- It has been found that most nations have not adopted the generic cost breakdown structure reported in RTO-TR-058 as their national life cycle cost breakdown structure. However, the NATO generic cost breakdown structure has been applied on specific multi-national programmes and some areas of enhancement are recommended.

  The current structure does not allow the identification of the life cycle cost results over the time phasing for national financial and programme contributions. Therefore, it is recommended to include two dimensions in addition to the Activity, Product and Resource dimensions. These additional dimensions are:
  - Time phasing; and
  - National contribution.

As the coding of the Generic Cost Breakdown is complex for non-experts, it is recommended to adopt a Generic Hierarchy for the GCBS.

O.9.6 Uncertainty and Risk

9) Risk and uncertainty analysis should be conducted at the same time as the life cycle cost estimate (Sub-section 7.9)

- Life cycle cost estimates of weapon system acquisition programmes are inherently uncertain and risky. To better support senior leadership, some sense of risk and uncertainty needs to be presented at the same time as developing the point estimate. This will present the decision maker with a comprehensive true view of the programme's likely eventual outcome.

10) The results of a life cycle cost estimate should be shown as a three point range of estimates (Sub-section 7.9)

- A life cycle cost estimate is not a single number, but rather a continuum or distribution of possible values.

O.9.7 Further Studies

The following paragraphs outline recommendations for further studies that would benefit the understanding and use of life cycle costing in NATO and multi-national environments.

- The next logical step would be to demonstrate the proof of concept (methods and models) described in the report by using a practical application of the guideline.
  - A typical example could be an existing NATO programme (but only using data that was available at the time) and/or any other multi-national programme (e.g. AWACS, AGS, JSF, NH-90, FREMM).
- Further research should be conducted in the area of capability portfolio analysis (see Chapter 9). This topic of joint NATO/PfP operational activities is becoming more important to NATO and, at present, there is insufficient information on how to evaluate the situation where a number of discrete assets share the information/data to provide a total capability solution.
  - An investigation into new methods and databases would support this requirement.
- Research into the life cycle costs of software. This report has not addressed software cost estimating as it was felt that this was a subject in its own right. Many academic studies are being conducted into open system architecture, modular construction and system behaviours that employ software intensive configurations.
  - Much is known about modern techniques in software development, but the issue of assessing software quality, reliability and support costs is still vague.
- Life cycle cost estimates are produced for a variety of reasons. It would benefit the NATO community to investigate how the cost estimates are being used in the decision making process.
  - This could avoid the situation where enormous effort may be spent in generating cost estimates when the answer could have been given in a more simplistic and effective manner.
- Estimating accuracy has been an issue for many years. An evaluation could be conducted that studied the delta between the original cost estimates and the actual costs.
  - This would provide a benefit by having a definitive document that could provide a view of estimating accuracy across a number of procurement processes.

- Research should be conducted continuously to enhance methods and models for life cycle costing (Sub-section 4.4).
    - Periodically, the US Department of Defense undertake an initiative to review the basis and techniques employed in cost estimating. This is supported by industry, a number of academic groups and learned societies. However, these initiatives purely examine techniques that will be employed within the US. It would be beneficial to conduct a similar continual review across NATO and PfP nations.
- The SAS-054 study gathered information on each nation's approach and use of models to generate life cycle costs. The study did not get a clear comprehension on the range of the functionality that could be provided by some of these models.
    - It would be of benefit to look in more detail on how these life cycle costing models generate cost for Research and Development, Production, Operating and Support.
- The issue of calibration, verification and validation of cost estimating models is of paramount importance. However, little or limited space is given in handbooks on the requirements and methods of validating cost models.
    - A study could be initiated to develop a common methodology for validating cost models, this would help to ensure cost estimating consistency across NATO and PfP nations on each nation's approach and use of models to generate life cycle costs.
- All life cycle cost estimates are only as good as the data that underpins the estimate. Much investment has been made in adopting ERP-systems to support financial and project reporting. The use of these systems in providing good quality data to support life cycle cost estimating is not clearly known.
    - A study should be conducted to evaluate the benefits or otherwise in adopting an ERP-system versus the investment in a bespoke system (e.g. VAMOSC) to assist the life cycle cost data collection process and improve cost estimating methods and accuracy.

Chapter 1 – INTRODUCTION

1.1 BACKGROUND

The Research Task Group on cost structures and life cycle costs for military systems (RTG SAS-028) developed a Generic Life Cycle Cost Breakdown Structure (GCBS) and associated definitions that could be used in any military programme to construct its own cost breakdown structure (Reference RTO-TR-058). The group also conducted an analysis on the way to use life cycle costs in the decision making process.

The participating nations proposed a follow on activity to examine methods and models for life cycle costing. This was assumed to be a set of techniques for cost modelling, cost prediction and analysing the life cycle costs of a system at any stage of its life.

At the November 2002 meeting in Brussels, the SAS Panel decided to form the Exploratory Team SAS ET-AH on methods and models for life cycle costing (SAS ET-AH). The SAS Panel recommended that the first meeting of the new group must be organised not earlier than March 2003 to allow time for national distribution and scrutiny of the SAS-058 Technical Report.

The first meeting of the SAS ET-AH was held over the 8th and 9th July 2003 in Brussels. The SAS ET-AH presented their Terms of Reference (TOR) and Technical Activity Proposal (TAP) for approval at the SAS Panel business meeting in November 2003. The team recommended a task group as the most appropriate way to conduct this study. The SAS Panel accepted this proposal at its November 2003 meeting, and at its March 2004 meeting the NATO Research and Technology Board approved a new Task Group SAS-054/RTG on "Methods and Models for Life Cycle Costing". The first meeting of SAS-054 took place on the 25th and 26th May 2004 at NATO Headquarters, Brussels, BELGIUM.

1.2 JUSTIFICATION

There is a long and documented history of both cost growth and estimating optimism within military programmes. This is particularly the case for multi-national programmes. The NATO ALP-10 –Guidance on Integrated Logistics Support for multi-national equipment projects (ILS) dated June 1990 (Reference NATO ALP10) states the following: multi-national equipment projects will be required to implement a life cycle cost programme. The purpose of this programme is to ensure that the developed system will have the lowest possible life cycle cost consistent with performance and schedule requirements. To achieve this goal, operation and support cost estimates assist designers and programme managers to focus their attention on those design aspects that drive costs. The process of generating realistic cost estimates is based on the application of appropriate methods and models. It is essential that future NATO programmes have a framework within which to start generating realistic and consistent life cycle cost estimates. The first step in this framework was to develop the generic life cycle cost breakdown structure under RTG SAS-028. The next step was to define methods and models within this framework which is the subject of this report.

The review and dissemination of the methods and models for life cycle cost estimates will enhance the procurement process where life cycle costs was a constituent part of the decision-making process. It was expected that the planned framework would:

- Ensure consistency of the life cycle costing approach within NATO programmes.
- Reduce the effort needed to conduct the life cycle costing analysis.
- Reduce the time schedule to conduct the life cycle costing analysis.
- Enhance individual nation's life cycle costing practices.

- Provide an understanding of NATO and PfP nations' methods and models.
- Provide guidance to nations not familiar with life cycle costing.

1.3 LIFE CYCLE COST MANAGEMENT IN NATO

1.3.1 Life Cycle Cost Management Purpose

Life cycle cost management (Reference: Life Cycle Management in NATO. A report to CNAD, edition 2, 2002) includes the processes required to determine which resources (people, equipment, services, material etc.) and what quantities of each should be used to perform project/system activities, develop an estimate, of the associated cost and allocate them to individual work items. These processes are aimed to estimate system life cycle cost for decision making and budget allocation and to ensure that the system activities are performed within the approved budget and according to the operational requirements fixed.

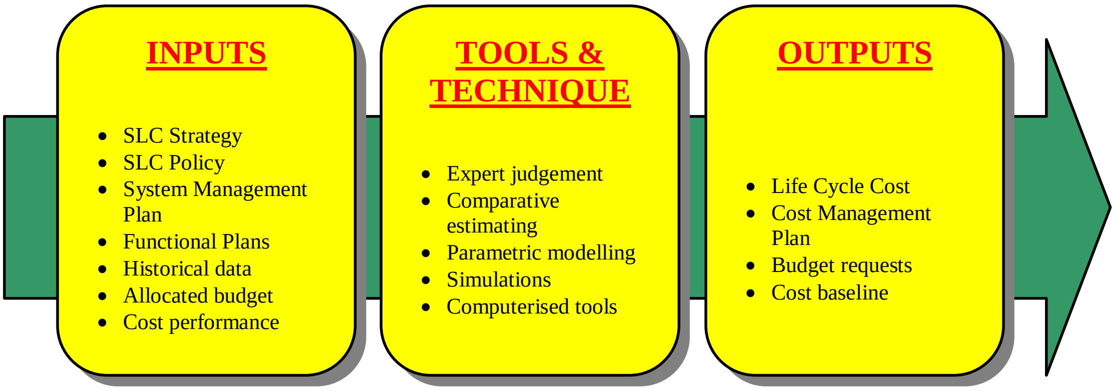

Figure 1-1: NATO Life Cycle Cost Management.

1.3.2 Life Cycle Cost Management Activities

- **COST PLANNING**
  - Develop the life cycle cost management plan and define the procedure by which the data are collected and managed.
  - Define the procedure for cost baseline allocation, change and configuration control.
  - Define the cost breakdown structure (CBS) that will be used throughout the system life cycle.
- **COST ESTIMATING**
  - Identify the activities related to the CBS and estimate the associated cost.
  - Establish a cost baseline for measuring life cycle cost performance improvement.
- **COST BUDGETING**
  - Allocate cost estimates to individual work items (related to the financial policy) in order to initiate the procedure for the allocation of the budget.
  - Monitor and record cost performance[1].

[1] In this context cost performance means the monitoring and control of the cost estimate against the actuals.

- **COST ASSESSMENT AND CONTROL**
  - Detect cost variances from baseline.
  - Assess the "why" of both positive and negative variances and their impact (level of risk) on LCC and the allocated budget.
  - Ensure that all appropriate changes are recorded in the cost baseline.
  - Initiate the change request procedure for the allocation of budget.

1.4 OBJECTIVES OF SAS-054

There are many methods and models available to conduct life cycle cost analysis. It was important to understand the applicability and boundaries of each method and model in order to recommend and use them appropriately when conducting life cycle cost analysis.

The core objective of the SAS-054 task group was to understand NATO and PfP nations' methods and models and promulgate good practice. The primary focus was on methods and models that were developed within member nations. However, it was pertinent to recognise that commercial methods and models form an important and integral part of the toolset available to cost estimators and analysts. In order to meet the above aspiration the following objectives for the SAS-054 Task Group were defined as:

- Review of cost forecasting models.
- Review of cost forecasting methods.
- Guidelines for the collection and understanding of cost related data for national and multi-national programmes.
- Treatment of uncertainty and risk.
- Guidelines for multi-national programmes.
- Awareness of new developments in methods and models.
- Review and possible enhancement of the NATO generic cost breakdown structure.

The final deliverable of the study is a technical report containing the outputs from the objectives above. It was also expected that the SAS-054 task group will implement additional mechanisms for presenting the results. This could take the form of a symposium, lecture series, workshops or other formats.

The task group was initiated in Spring 2004 and submitted its final report to the SAS Panel at the Fall 2006 meeting.

1.5 SAS-054 STUDY APPROACH

At the initial meeting a matrix was developed for capturing the methods and models used by all the participating nations. This comprised a number of questions (see Table 1-1) that were applicable to each of the NATO Phased Armaments Programming System (PAPS) (The handbook was published in February 1989 as AAP-20 (Allied Administrative Publication) by the Defence Support Division of the NATO International Staff).

The responses from the questionnaire were used to understand and debate the issues that were relevant to life cycle costing. In this way information was captured in a cohesive and auditable manner. Each nation was then allocated a task that could be presented at a collective meeting and thoroughly discussed to gain a clear understanding of the topic. The completed matrix for each nation is given at Annex A.

Table 1-1: Summary Matrix Questions for Each Participating Nation

Question	Description
Indicate the type of costing studies required.	Nations were to state the reason for undertaking the cost study and show what the output was used for.
Description of the process or national guideline to be followed – how are we going to do this?	Nations were to state if there is a national guideline or process to be followed.
What methods are used?	Nations were to state the methods (Reference: Chapter 4) used at the different phases of the life cycle.
What models are available? – Commercial models.	State the commercial off the shelf (COTS) models (Reference: Chapter 5) used to achieve the required costing outputs.
What models are available? – In-house developed models.	List any formal models (Reference: Chapter 5) that had been developed in-house. Ideally these models would have been verified and validated as being "fit for purpose".
Requirements to apply national guideline.	State if mandated by national government approval authorities or by departmental procedures.
Requirements to apply methods.	State if mandated by the national government approval authorities or by departmental procedures.
Requirements to apply models.	State if mandated by the national government approval authorities or by departmental procedures.
Restrictions on applicable methods or models depending on the goal.	State any barrier that may cause the method or model to be either unworkable or to rely on subjective judgement instead of data.
How can data be collected?	State if any automated system is used for collecting data (Reference: Chapter 6).
How is risk and uncertainty considered?	State the method used to identify, collect and analyse risk and uncertainty data (Reference: Chapter 7).
What models and tools are available to assess uncertainty?	State the commercial or in-house models used to produce stochastic or deterministic results through Monte Carlo modelling.
What models and tools are available for risk analysis?	State the commercial or in-house models used to collect and manage risk information.
Requirements to apply risk methodology.	State if risk assessment methodology is mandated by national government approval authority or departmental procedures.

1.6 IMPLEMENTATION OF THE GUIDELINE

The use of life cycle costing should be encouraged both within government departments and defence contractors. Therefore, the overall objective of this report is to produce a guideline that can be used by NATO and PfP nations, defence contractors and equipment suppliers in both national and multi-national programmes. To achieve this, the implementation process for the guideline may include:

- Advertising and publishing the guideline.
- Developing some examples to demonstrate the life cycle costing process that can be adopted at the various stages of the product life cycle.
- Organising technical seminars, lecture series and workshops.
- Develop an improved NATO Standardisation Agreement (STANAG) on life cycle costing. However, this would have to explicitly describe in detail how it should be conducted and what is realistically achievable at each stage of the life cycle.

The above list is not exhaustive and other implementation approaches may be considered. However, to be successfully conducted by NATO and PfP nations and equipment suppliers it will be essential to disseminate the life cycle costing process and techniques together with worked examples in order to gain the support of everyone.

During the study, SAS-054 contacted the life cycle management group (AC/327). One of the tasks of this group is the responsibility for the development of NATO policies (e.g. STANAGs) related to life cycle management. In December 2005, the AC/327 subgroup B working group 3 was established. This working group is tasked to develop guidance on the application and implementation of NATO policy relating to life cycle costing in support of the NATO System Life Cycle Management (SLCM) policy (Reference. C-M(2005)0108-AS1 dated January 2006).

The working group (AC/327) is the official and proper body to implement the RTO SAS-054 guideline within NATO and PfP nations.

Further details on the work of AC/327 subgroup B Working Group 3 can found in their Terms of Reference (Reference: PFP(AC/327-SG/B)D(2005)0003 dated December 2005).

1.7 STRUCTURE OF THE REPORT

In addition to this introduction, the structure of the report comprises the following chapters.

Chapter 2: Describes the role of life cycle costing in the decision making process. It examines the scope to be considered, its limitations and purpose in terms of budget planning, option analysis and cost reduction.

Chapter 3: Provides a detailed insight into life cycle costing activities across each of the NATO PAPS phases.

Chapter 4: Gives details on the life cycle costing methodologies that can be employed during each of the NATO PAPS phases.

Chapter 5: Discusses life cycle costing models in terms of what is available, the appropriate applications and a brief on current models employed by NATO and PfP nations in conducting life cycle costing and subsequent cost analysis.

Chapter 6: Discusses the issues and considerations found when examining each nation's processes for data collection to support the life cycle costing activities.

Chapter 7: Provides the basis for the measurement of uncertainty and risk and how this should be used in life cycle costing and subsequent cost analysis.

Chapter 8: Considers any other life cycle costing issues and considerations that have been identified during the study.

Chapter 9: Highlights new developments in life cycle costing and cost analysis.

Chapter 10: Discusses any enhancement to the SAS-028 cost breakdown structure as a result of this study.

Chapter 11: Provides a summary of the findings and conclusions.

Chapter 12: Provides the recommendations.

Annex A: Provides the completed matrix completed by each nation.

Annex B: Provides examples of data forms for capturing the costs at the production phase.

Annex C: Provides examples of typical life cycle cost questionnaires.

Annex D: Provides a list of life cycle cost definitions.

Annex E: PAPS milestone definitions.

Chapter 2 – THE ROLE OF LIFE CYCLE COSTING

2.1 GENERAL

The use of life cycle costing should, in each phase of the programme, support the process by which managers can make the best decisions on options presented to them. These options may include evaluation of future expenditure, comparison between alternative solutions, management of existing budgets, options for procurement and evaluation of cost reduction opportunities. Life cycle costing is also used for affordability assessment and determining the cost drivers associated with the Key Performance Indicators or Key User Requirements.

Life cycle costing must be used as a benchmark against which options can be measured for ‘value for money’ during the acquisition/production and in-services phases. However, it must be appreciated that the greatest opportunities to reduce life cycle costs usually occur during the early phases of the programme (as shown in Figure 2-1). It follows therefore that life cycle costing is used as a decision and optimisation criterion in the search of the best compromise between performance, cost and time.

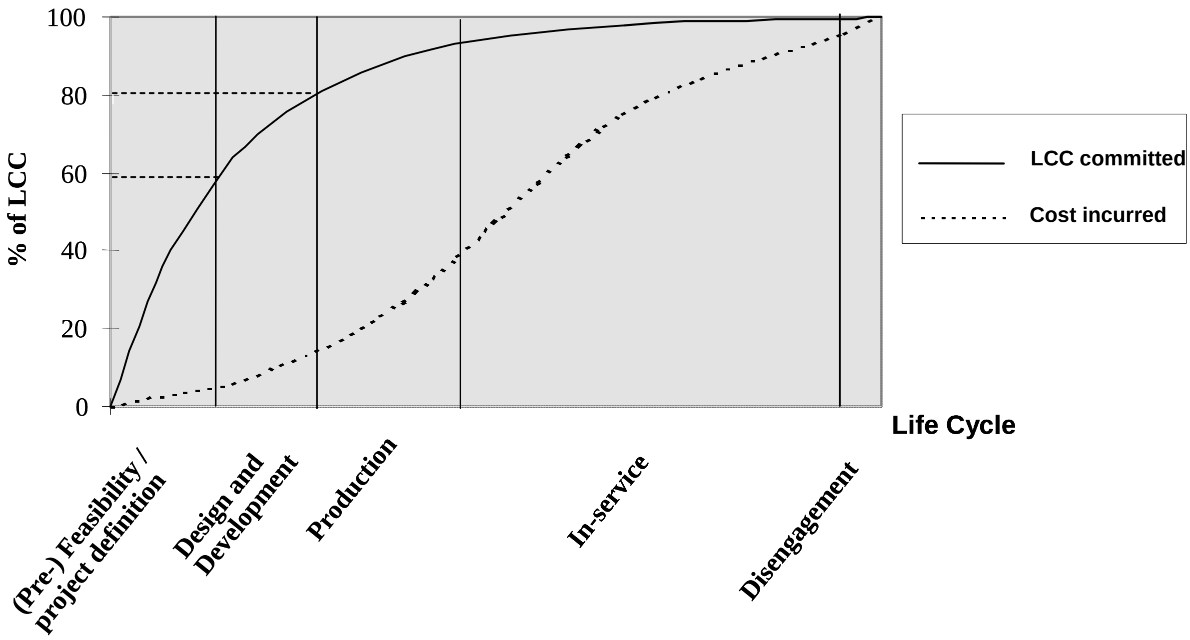

Figure 2-1: Traditional LCC Committed versus Incurred Cost Curve.

Life cycle costing should not be considered as a one-off task, but should be recognised as an ongoing activity throughout the life cycle to evaluate all programme changes and exploit cost saving opportunities.

Although this report focuses on the importance of conducting life cycle cost analysis, it should be recognised that there are limitations of such an analysis. Some of the limitations are (Reference: LCC Tutorial by Paul Barringer and David Weber):

- Life cycle costing is not an exact science. A life cycle cost analysis does not provide an exact number of the costs; it merely gives an insight in the major cost factors and an insight into the magnitude of the costs.
- The life cycle cost estimate is only an estimate. Estimates can never be more accurate than the inputs and the inputs are often estimates themselves or expert opinions.

- Life cycle cost models require volumes of data and only a few handfuls of data is likely to exist when conducting the estimate. Therefore many assumptions have to be made. The life cycle cost estimate therefore only counts given the assumptions used. If one of the assumptions changes, it is possible that the cost estimate will change too.
- Life cycle cost results are used for several purposes and, in some instances, are not compatible. For example, the life cycle cost used for a comparison or a trade-off study may not always be suitable for budgeting purposes.

These limitations should be carefully considered when conducting a life cycle cost analysis.

2.2 PHASES AND THE USE OF LIFE CYCLE COSTING

It is recognised that individual nations may use their own nomenclature for these early phases (e.g. user requirement, system requirement, etc.) and may conduct their own pre-feasibility or early conceptual work to assess the level of their capability gap. For clarity and consistency the NATO nomenclature has been used throughout. However, the processes and techniques described here are equally applicable to national and multi-national programmes.

Early in the project life cycle, studies need to address the capability gap, the numbers of equipment or platforms required and the technologies that can help to fill the gap at lowest cost. This requires a ‘strategic’ approach that can provide a capability to look at the ‘big picture’. At this phase in the life cycle it is unlikely that the costs can be identified in a great deal of detail, rather an understanding of the holistic[1] values (i.e. the whole is more than the sum of its parts) in terms of the primary cost breakdown structure elements and the uncertainty surrounding these figures is required. The level of life cycle costing at this phase will support the NATO MND (Mission Need Document) and ONST (Outline NATO Staff Target). It is important to recognise in these early phases that only broad estimates or a range of estimates will be available – it is more important to ensure that they are as complete as possible (e.g. nothing large is missing).

Once the NST (NATO Staff Target) has been developed, the focus turns to the performance, cost and time envelope of various options that will meet the NST. Forecasts of the likely life cycle costs for new equipment(s) and platform(s) are needed so that the cost breakdown structure can be developed and extended to reflect the acquired knowledge of the expected system characteristics and associated costs. The life cycle costs at this phase will support the NSR (NATO Staff Requirement) by providing reasonably accurate estimates of development and production costs. However, due to the likely lack of design data the in-service costs will be more uncertain. During the project definition phase the usage patterns and system design will mature to provide a much improved basis for establishing more accurate in-service costs.

When the preferred options are identified, industry is generally asked to provide information and compete for its supply. Assessments of the bids are conducted on a life cycle cost basis and need to address all the economic and financial requirements set out by each nation. At this stage the cost breakdown structure should be fully developed such that all the cost elements are identified.

For in-service equipment a forecast of the costs for the remaining life is required. This will assist in any budget adjustment studies and provide a realistic baseline upon which to measure and compare with the effect of change due to utilisation, incremental updates, overhauls or even the procurement of new equipment.

[1] The literal meaning of “holistic” is that all the properties of a given system cannot be determined or explained by the sum of its component parts alone. Instead, the system as a whole determines in an important way how the parts behave.

In summary, it is not possible or desirable to collect and analyse information at the same level of detail throughout the life cycle although there should be a common thread in terms of programme phases, cost breakdown structure grouping and resource consumption. What should be seen is a life cycle cost estimate that evolves, in terms of detail, as the programmes progresses through the different phases.

Further discussion on the processes and methods applicable to each phase of the project life cycle is given at Chapter 3.

2.3 APPROACH TO LIFE CYCLE COSTING

Prior to any costing activity it is essential to define what is to be estimated and understand what the estimates will be used for (e.g. setting budgets, options evaluation, pricing, etc.). The system under consideration could range from a large turnkey project (e.g. a major capital investment including buildings and infrastructure), a stand-alone system (e.g. individual platforms such as a ship, aircraft or tank), or a worldwide application (e.g. theatre(s) of operation and use). The approach to be adopted needs to be tailored to suit the questions to be answered, the costing requirements and the availability of suitable data.

With some variation (to the level of detail), the same basic approach to life cycle costing can be applied to all projects regardless of their specifications. This approach encompasses the following steps that are more fully described in the subsequent sub-sections. The steps are:

- Define the aims and objectives of the study.
- Establish the programme content, the costing boundary and the assumptions for the study.
- Develop the structure of the life cycle cost framework.
- Establish the data and populate the life cycle cost framework.

Once the scope of the study has been established the overall cost estimating process can commence as shown in Figure 2-2. It may be necessary to undertake several iterations following the first set of results due to the availability of more data, clarification of the assumptions or just general refinement. The process is completed with the presentation of the results, assumptions and financial implications.

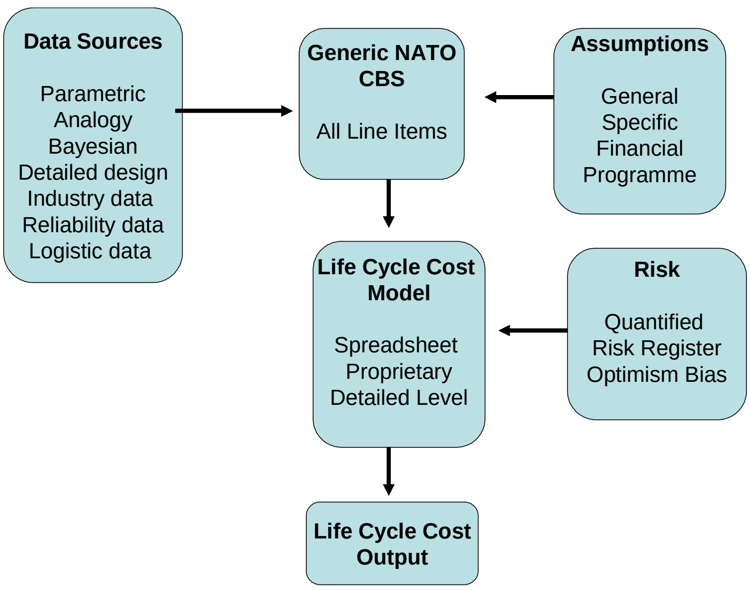

Figure 2-2: Generic Life Cycle Cost Estimating Process.

2.3.1 Define the Aims and Objectives

The aim and the objectives of the study will have a major impact on the way a study is conducted. A different type of question will result in a different way of conducting the study. This will often be implicit in the type of study being undertaken, but it needs to be clearly and unambiguously defined if the life cycle cost study is to provide useful and meaningful results. An overview of the type of studies to be conducted can be found in Section 2.6. Early procurement phases will concentrate on assessing affordability, option analysis, etc., when the level of data to support a life cycle cost analysis is sparse. It is essential therefore to undertake several iterations of the process due to clarification of the assumptions and general refinement of the data. This stage would also include the definition of the systems and/or options to be studied.

2.3.2 Establish the Costing Boundary and Assumptions

The Costing Boundary defines exactly what cost elements will be included in the study and the level of detail in which they will be considered. The level of detail of the study is also dependent of some external factors, like the maximum duration of the study, the financial means available to conduct the study, the availability of qualified personnel to conduct the study, the availability of experts to provide information and the availability of data.

There are three boundaries to consider. The first boundary relates to the definition of the system itself particularly the elements for costing. It is worth describing the total system and then agreeing with the stakeholders those elements that are outside the scope of the study. In this way a clear picture is drawn which helps to avoid any confusion later in the study.

The second boundary definition addresses the timescale aspects so as to establish which programme phases have to be included, e.g. phased procurement, phased implementation, incremental build standards, in-service date and the likely operating life of the proposed system (see Sub-section 2.8.3 for details of the time period consideration to be made).

The third and last boundary consideration defines what will be included within the scope of the study. This can range from the simple cost of buying a piece of equipment to the total cost to the government or industry of developing, procuring, operating, supporting and disposing of a complete range of such equipment.

To ensure completeness, a full list of all possible cost elements should be first drawn up which covers all phases in the project life cycle. These cost elements should then be reduced by elimination of those falling outside the specified cost element boundary. This costing framework should be based on the NATO generic cost breakdown structure (Reference: RTO-TR-058 report). In Chapter 10 some enhancements to this cost breakdown structure are suggested.

Figure 2-3 shows an example (taken from ANEP-41) on how the costing boundary expands firstly from just considering an equipment purchase (equipment buy) to the involvement in a development and production programme (procurement programme) and then into inclusion of the in-service costs. Further costs such as capability upgrades, etc., are included if the intention is to provide a forecast of future cost expenditure over the life of the programme. The costing of the final element shown is dependent upon each national requirement. Typically, an apportionment based on the expected use is agreed with the respective stakeholders and is added to the cost estimates for completeness.

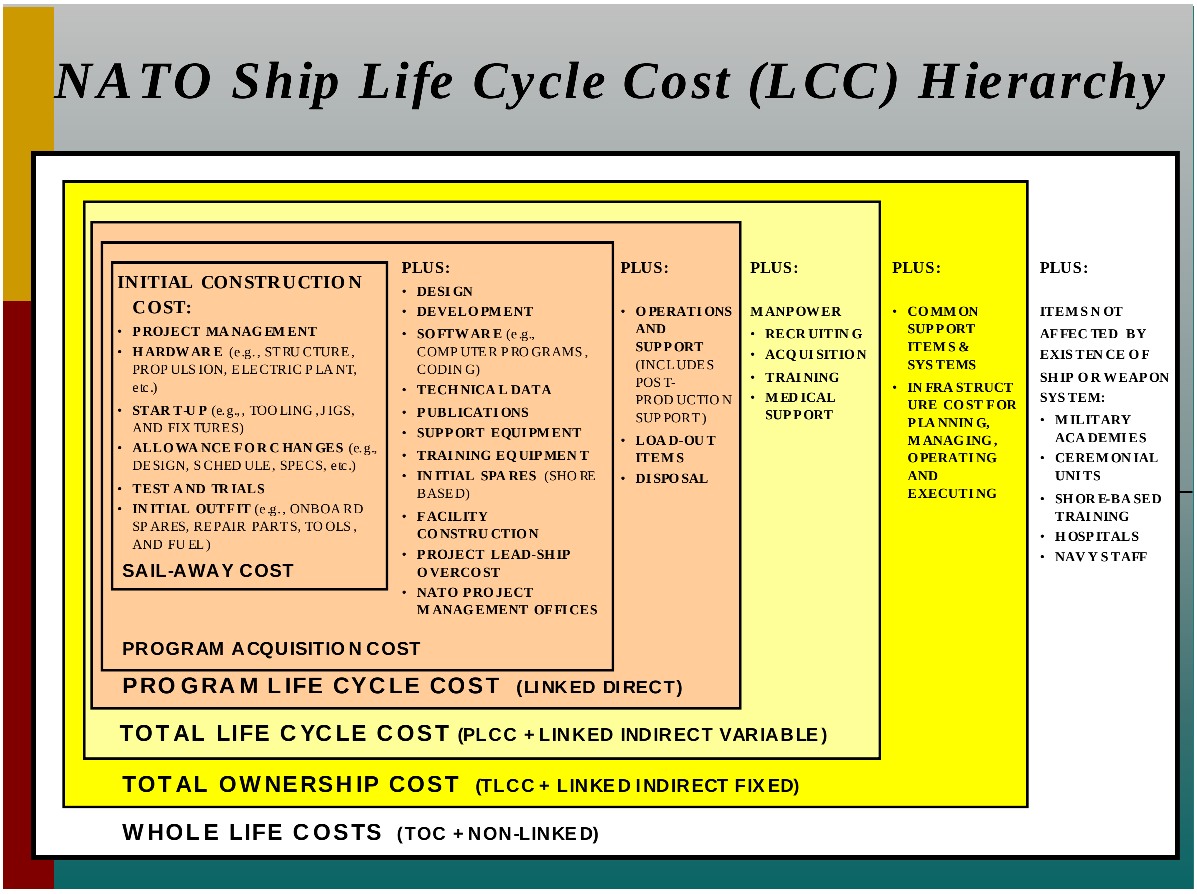

Figure 2-3: Typical Life Cycle Cost Boundary.

Whenever an estimate is undertaken, it is necessary to create a series of statements that define the conditions upon which the estimate will be based. When conditions are directed upon the estimator, they become the ground rules by which the estimate will be conducted. In the absence of a firm ground rule the estimator can define assumptions. Because of the potentially significant cost implications of key assumptions and ground rules, it is good practice to undertake a sensitivity analysis of them.

It is essential that all the data, ground rules and assumptions are captured and recorded so that there is a complete audit trail to the estimate. There is no NATO document that reflects this requirement. The next sub-sections describe how the UK and the US capture and record this.

2.3.2.1 UK Master Data and Assumptions List

The UK Ministry of Defence use and recognise a MDAL (Master Data and Assumption List) (Reference: www.ams.mod.uk). This is a comprehensive document that records all the data used in compiling the estimate and all the respective stakeholders are expected to sign that they agree with the data and assumptions recorded in the document. The process can be considered as laborious and time-consuming (but is essential) and in rapidly changing studies (e.g. pre-feasibility and concept) the requirement for a fully completed MDAL becomes cumbersome and constraining. This is overcome through the development of an abbreviated form of MDAL which may only be a few pages, but will contain all the salient points. This will be developed by the life cycle cost analyst and presented to the stakeholders for agreement. Developing the document in this manner ensures that the estimates can be produced rapidly and consistently to support option analysis and affordability assessment studies.

2.3.2.2 US Cost Analysis Requirements Description

In the USA a process is adopted to establish the costing boundary; this provides the basis for the cost estimate. For major acquisition programmes, the CARD (Cost Analysis Requirements Description) is used to formally describe the acquisition programme (and the system itself) for the purposes of preparing both the programme office cost estimate and the US Department of Defense Component[2] cost position, if applicable and the OSD CAIG independent cost estimate[3].

The CARD is prepared by the programme office and approved by the DoD Component Programme Executive Officer (PEO). For joint programmes, the CARD includes the common programme agreed to by all participating DoD Components as well as all unique programme requirements of the participating DoD Components[4].

The CARD typically provides both narratives and tabular data, roughly following the following outline:

- All ground rules and assumptions to be used in developing the cost estimates.
- System description and characteristics.
  - System work breakdown structure.
  - Detailed technical and physical description.
  - Subsystem descriptions, as appropriate.
  - Technology maturity levels of critical components.
- System quality factors.
- Reliability/Maintainability/Availability.
- Project Managers' assessment of programme risk and risk mitigation measure.
- System operational concept.
  - Organisational/unit structure.
  - Basing and deployment description (peacetime, contingency, and wartime).
- System support concept.
  - System logistics concept.
  - Hardware maintenance and support concept.
  - Software support concept.
  - System training concept.
- Time-phased system quantity requirements.
- System manpower requirements.
- System activity rates (OPTEMPO or similar information).
- System milestone schedule.
- Acquisition plan or strategy.

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[2] A "Component" is a military department or a defence agency.

[3] DoD Instruction 5000.2, Enclosure 3 specifies that for major defence acquisition programmes the CARD will be provided in support of major milestone decision points.

[4] DoD 5000.4-M, DoD Cost Analysis Guidance and Procedures, Chapter 1 provides further guidelines for the preparation of the CARD.

For each topic listed above, the CARD should provide information and data for the programme to be costed. In addition, the CARD should include quantitative comparisons between the proposed system and a predecessor and/or reference system for the major topics, as much as possible. A reference system is a currently operational or pre-existing system with a mission similar to that of the proposed system. It is often the system being replaced or augmented by the new acquisition. For a programme that is a major upgrade to an existing weapon platform, such as an avionics replacement for an operational aircraft, the new system would be the platform as equipped with the upgrade, and the reference system would be the platform as equipped prior to the upgrade.

Clearly, much of the information needed for the CARD is often available in other programme documents. The CARD should stand-alone as a readable document, but can make liberal use of appropriate references to the source documents to minimise redundancy and effort. In such cases, the CARD should briefly summarise the information pertinent to cost in the appropriate section of the CARD, and provide a reference to the source document. The source documents should be readily available to the programme office and independent cost estimating teams, or alternatively can be provided as an appendix to the CARD. Figure 2-4 illustrates the process.

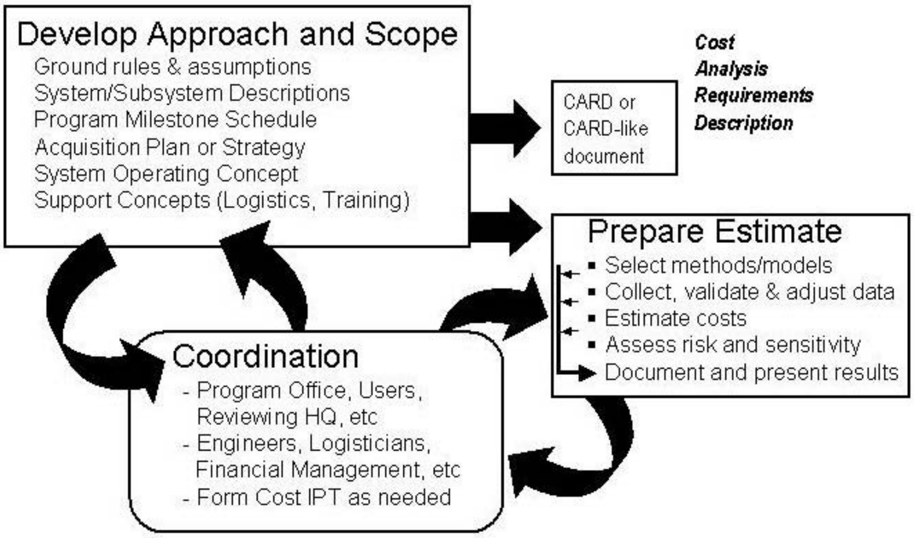


Figure 2-4: USA Cost Analysis Process.

It is recommended that all the assumptions used and recorded be questioned by an independent technical team.

2.3.3 Develop the Structure of the Life Cycle Cost Framework

Having established the costing boundary this will set the requirements for the life cycle cost framework (e.g. the implementation could be a spreadsheet or more advanced modelling techniques). The costing framework should take account of both the immediate needs of the current phase and also to be adaptable to the developing needs of later phases.

The structure of the framework will be based on the requirements previously discussed at Sub-sections 2.3.1 and 2.3.2. A typical outline for a generic life cycle cost model is shown at Figure 2-5.

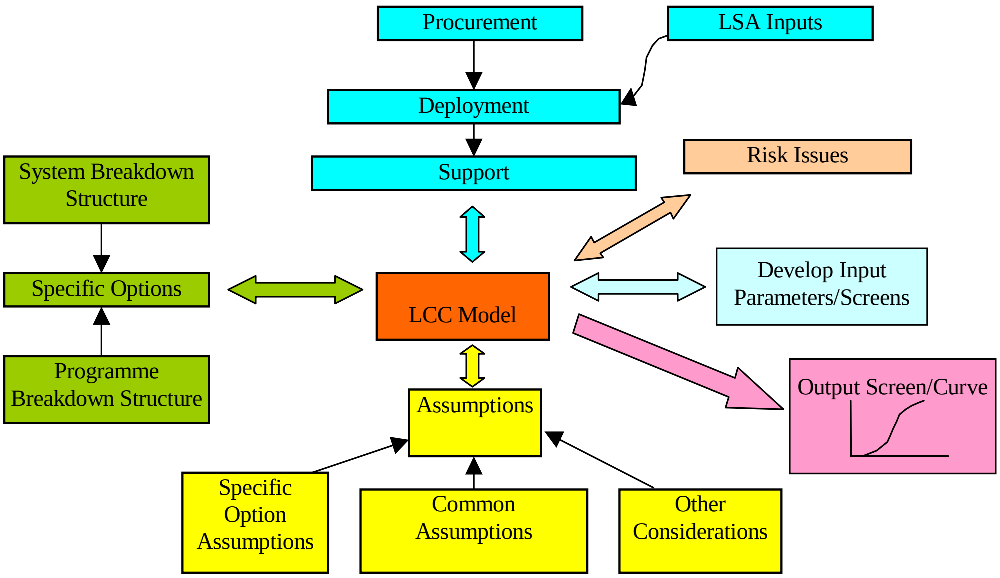


Figure 2-5: Example of a Typical Life Cycle Cost Framework Structure.

The figure shows the framework broken down into a number of areas. On the left (in green) would be the cost breakdown structure reflecting the system, any specific options relating to the system and details of the programme timescale. On the top (in blue) would be the programme documentation relating to procurement strategy, how the system will be deployed in operational and peacetime use and how it will be supported in these environments. The ILS (Integrated Logistic Support) and the LSA (Logistic Support Analysis) inputs would support the understanding of the proposed deployment. At the bottom (in yellow) would be the ground rules and assumptions. These would be recorded in a document and the information would be used to populate the areas of the model where no hard data was available. On the right hand side, the risk issues could be included within the model so as to obtain a 'risk adjusted' cost. To avoid an over complicated implementation it may be necessary to develop some suitable input and output screens to assist the user.

It is essential that all life cycle cost models are robustly tested and validated to ensure the correct operation of the equations in relation to the input attributes.

2.3.4 Establish the Data and Populate the Life Cycle Cost Framework

Once the structure of the life cycle cost framework has been established, the cost breakdown structure needs to be populated. The cost breakdown structure will comprise a number of cost elements. These cost elements will need to be estimated. The method of establishing the estimate will depend on the availability of the data. An overview of the methods to estimate costs can be found at Chapter 4.

Typical methods employed to gather data are:

Market Survey

This is usually good for gathering technical data, but limited in obtaining prices. Any costs obtained are likely to have a large margin of error and will have little or no substantiation.

Industrial Visit

This will produce information and data on the product, but it is unlikely that the companies will provide anything more than broad order cost and again with no substantiation.

Data for Direct Use Within the Study

This would be actual costs or estimates directly relating to the breakdown of the system. Actual equipment procurement costs, published data for equipment and services, etc., could fall directly into this category. A considerable element of these costs will be based on current records and may be held by specialist cost estimating departments or consultancies.

Data on Analogous Systems

This could be low level, technical and other data on the system under consideration for use in parametric or other modelling methods to derive the required information. Size, weight, complexity, reliability could be examples of this kind of data.

Data from Logistic Analysis

This would be information and data from ILS (Integrated Logistic Support) studies to provide data on component reliability, maintainability and supply chain information. The cost estimator should be aware of the following essential ILS information to support the life cycle costing (accepting that some of these will not be available in the early phases of the programme).

The work frame and interfaces of the ILS Programme for a generic defence system are described in an ISP (Integrated Support Plan). This is the main ILS management plan. Specific plans are applicable to the ILS Programme, for example (but not exclusively) the following:

- LSAP (Logistic Support Analysis Plan).
- Reliability and Maintainability Programme Plan.
- LCC (Life Cycle Cost) Plan.
- MANPRINT (Manpower and Personnel Integration) Plan.
- LORA (Level of Repair Analysis) Plan.

The LSA (Logistic Support Analysis) constitutes the on-going iterative analytical process that is employed to:

- Assess a given or assumed configuration in terms of its inherent supportability characteristics.
- Identify the ultimate support requirements for that configuration.

It should be emphasised that the results from the LSA contribute to life cycle cost in two distinct ways:

1) The application of the analysis provides data from which life cycle costs are derived; and

2) LSA results contribute to the reduction of life cycle costs by indicating the support cost drivers for the system and thus providing feedback for the ILS design influence.

The life cycle cost evaluation (see Figure 2-6) is based on the life cycle cost modelling effort, which in turn takes advantage of the Use Study to establish the full range of operational parameters necessary for the calculation of realistic costs.

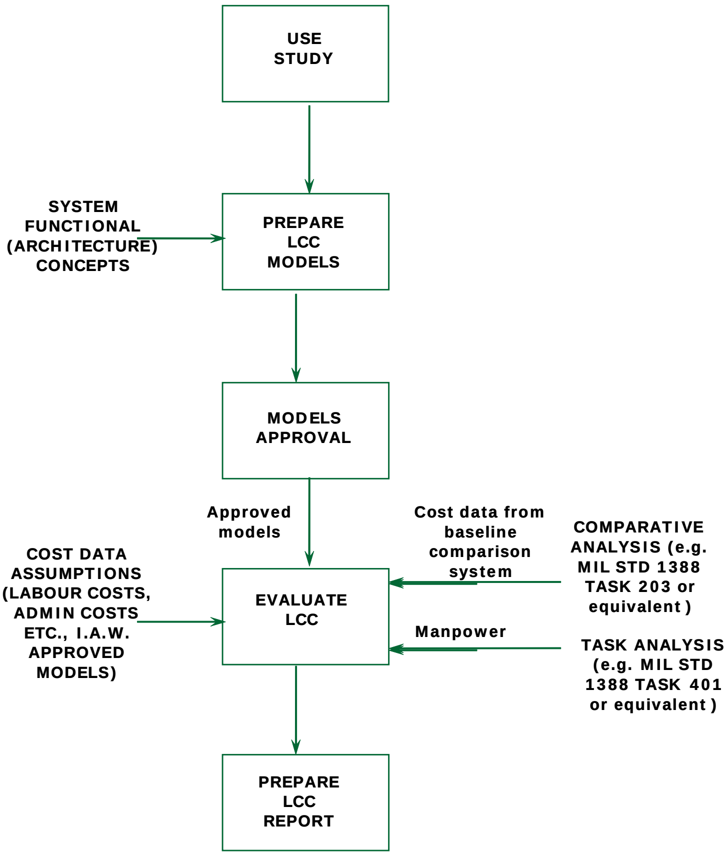


Figure 2-6: Process Flow for Determining LCC Support to Logistic Analysis.

Additional inputs to the life cycle cost evaluation can come from the execution of LSA Task 203 (Comparative Analysis) and Task 401 (Task Analysis).

The purpose of Task 203 is to identify, by using comparative elements, supportability problems that have arisen in the employment of systems already in service and to identify supportability, cost and readiness drivers that must be considered as critical in the comparative system design.

As regards Task 401, its purpose is to focus on potential critical support elements and to influence the system design in order to reduce the impact of critical support elements.

The LSA task results are documented in the LSAR (Logistic Support Analysis Record) to identify and develop logistic support resources.

The LSAR database is initiated early in a programme to capture logistic requirements, identify functional logistic breakdown structure and document the initial results of the LSA tasks. Prior to the production phase, the LSAR database is used to: identify the complete logistic breakdown structure; control logistic performance of the system; identify operating and maintenance tasks, logistic support resources and transportability characteristics. During the production phase, the LSAR database is used to update the identification data due to configuration changes, document the LSA task updates and document the results of validation of the technical documentation. During the in-service phase, the LSAR database is used to capture R&M (Reliability and Maintainability) data related to the use and support of the system, update logistic data due to configuration changes, manage obsolescence and the effect from any maintenance organisation changes.

Figure 2-6 illustrates how the information flow from various documents and studies are combined in order to provide the life cycle cost to support logistic analysis studies.

2.4 CONDUCTING THE COST ANALYSIS

The level of analysis required by different studies varies considerably. In some circumstances, simple accountancy calculations involving discounted cash flow may be all that is required. Cost analysis would traditionally include the testing of parameters and assumptions by means of sensitivity analysis. Testing of alternative assumptions by means of "what if" analyses should also be conducted. It is essential that any life cycle cost model has the ability to support these types of analyses so that the decision-makers have a full understanding of the costs and the financial implications.

Quantitative cost risk analysis may also be employed to either gain more insight into specific risk areas or to evaluate a programme's overall exposure to risk. A key feature of this approach to analysis is that it should provide forecasts and insights based on complex combinations of risks and uncertainties, as could occur, for example on major projects. Commonly used techniques include Monte Carlo analysis and System dynamics. Figure 2-7 shows the benefit of conducting cost risk analysis in addition to the more traditional accountancy methods of establishing financial outcomes.

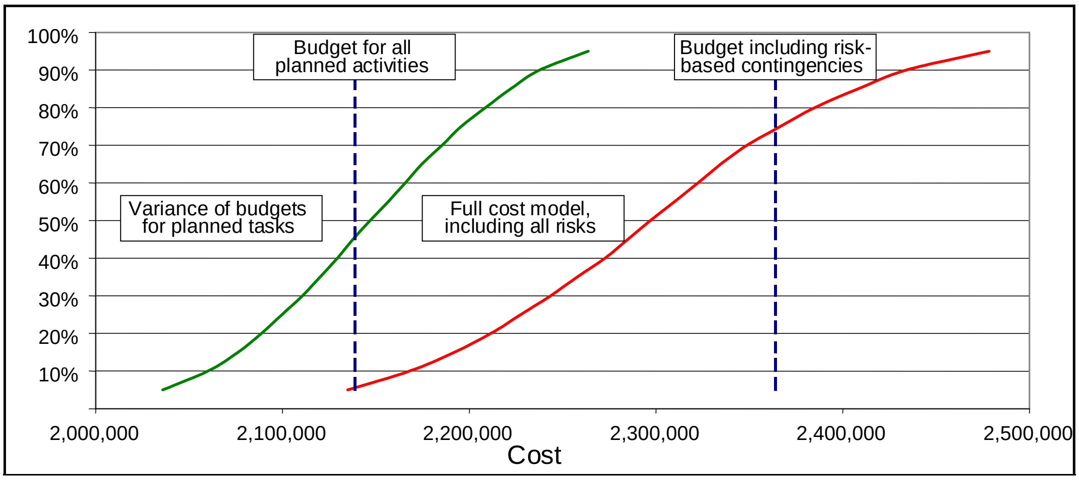


Figure 2-7: Cost Risk Analysis Outputs Example.

The first curve (green) represents the uncertainty in the cost estimate arising from uncertainty in the data and methodology employed in developing the estimate. The second curve (red) represents the extent of the risk in the programme arising from the relevant risks recorded in the programme risk register. In examining both curves the decision maker can establish the level of acceptable financial risk dependent upon the confidence in the cost estimate. More details on uncertainty and risk analysis can be found in Chapter 7.

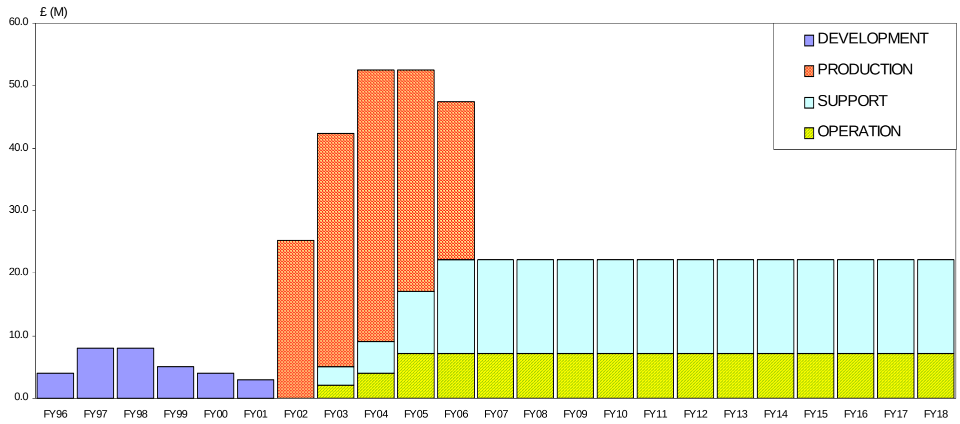
2.5 PRESENTATION OF THE LIFE CYCLE COST RESULTS

Summaries of the life cycle cost outputs and the underlying assumptions should be discussed with the stakeholders at the earliest opportunity. This will allow for changes and refinements to be incorporated prior to the issue of a final report. The objective at all times is to ensure the life cycle cost study is meaningful and fully meets all the stakeholders' needs.

The results of cost studies can be presented in a wide range of tabular and graphical forms. The favour is to include graphical presentations of the results wherever possible. This enables the widest possible

audience to have a clear picture of the overall results while retaining the detailed tabular presentations for those that require them.

Two common form of graphical presentation (the spend profile and cost allocation pie chart) are shown as Figures 2-8 and 2-9. These figures indicate costs at a high level, but can also be used to present a more detailed level as required. For presentation purposes these costs have been truncated at Financial Year (FY) 18.



£ (M)	FY96	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18
DEVELOPMENT	4.0	8.1	8.1	5.1	4.0	3.0																	
PRODUCTION							25.3	37.4	43.4	35.4	25.3												
SUPPORT								3.0	5.1	10.1	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2
OPERATION								2.0	4.0	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1

Figure 2-8: Example of a Baseline Life Cycle Cost Spend Profile.

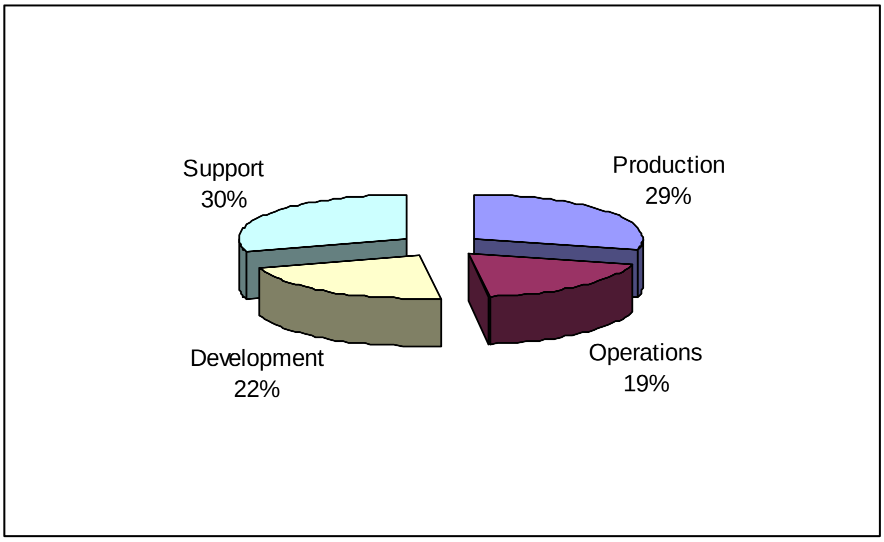


Figure 2-9: Example of a Life Cycle Cost Allocation.

Note: The cost allocation percentage shown in the example above should not be considered as being representative of all life cycle cost estimates.

The product of the life cycle cost study should be a report incorporating the results and conclusions as well as a presentation on the basis of those results. It should include a full definition of the aims and conduct of the study, the definitions of the options studied, the costing boundary considered and the assumptions underlying the cost elements. This work should also be continuous to support the life cycle management of the programme.

The figures above represent single point estimates with no consideration to the presentation of uncertainty and risk. ***Figure 2-10 presents a recommended approach for communicating results of a life cycle cost estimate to senior decision makers.***[5] The top line shows a three point range of estimates, and conveys the idea that a cost estimate is not a single number, but rather a continuum or distribution of possible values.

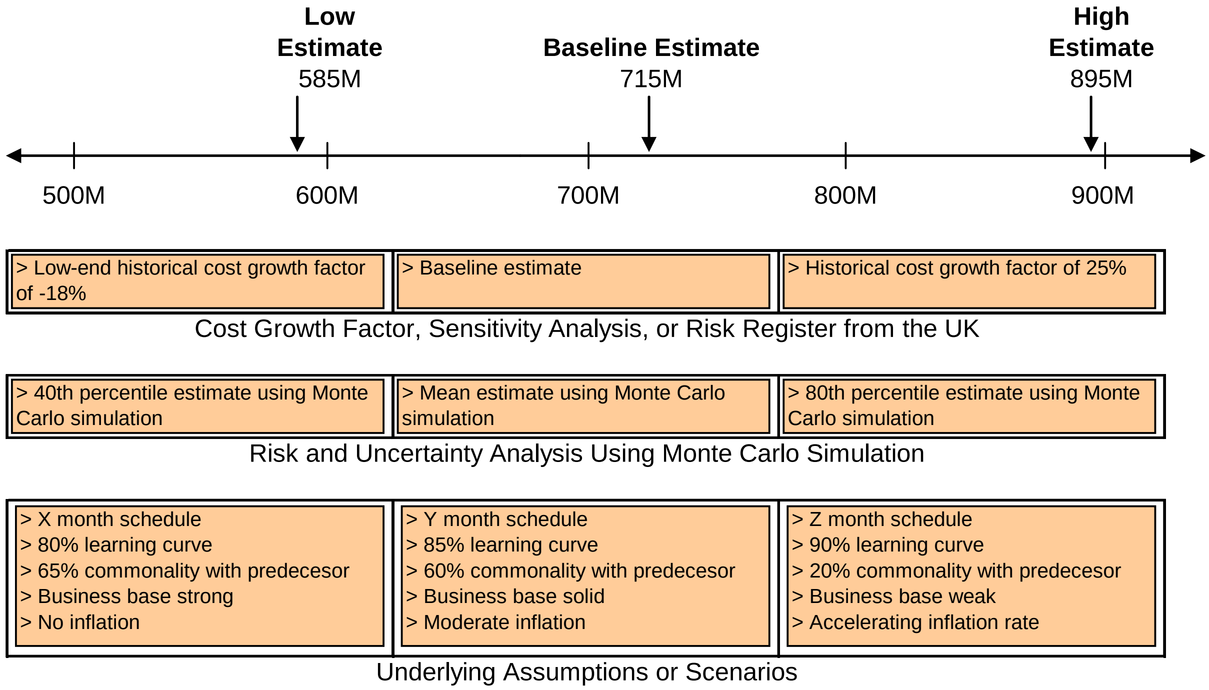


Figure 2-10: Recommended Presentation of Cost Estimating Risk Analysis.

Analysts can use one or more estimation techniques in performing risk and uncertainty analysis. Some of these are shown in the top two bars or sections of the figure. The bottom section, which should always be included in the presentation of the estimate, shows all of the assumptions or scenarios associated with the low, baseline, and high estimates. Including this section enables decision makers to see clearly the cost implications of events that can influence the outcome of an acquisition programme.

This approach will lead to the establishment of a sound, well-structured methodology for the conduct of and presentation of life cycle cost estimates.

2.6 FINANCIAL THRESHOLD

Some nations have set a financial threshold for conducting life cycle costing studies. For example, in The Netherlands a life cycle cost analysis (as part of the defence materiel process) is performed for all projects with a total budget in excess of €5 M. Others have no limits, but are determined by:

[5] U.K. Ministry of Defence and **Impossible Certainty**, RAND, 2006, pages 84-86.

- The level of detail required.
- The benefit the life cycle costing study will bring to the programme.
- The rigor necessary to support the business/programme investment.
- The likely effort to be expended.

It is recommended that each nation sets its own threshold value and that it should be determined in terms of total programme cost, political requirements and timeliness.

2.7 ORGANISATION AND OWNERSHIP OF THE LIFE CYCLE COST

The life cycle cost analyst or manager should be the owner of the development of any life cycle cost estimate and the configuration management of the supporting documentation.

The role of the life cycle cost analyst is to ensure the smooth running and facilitation of the total life cycle cost management process. In summary, the analyst should be responsible for:

- Ensuring that an appropriate life cycle cost management plan is in place and updated where necessary.
- Supporting the programme by providing robust and credible life cycle costs in a timely manner.
- Ensuring that the life cycle costing process is appropriate, workable and supports the programme requirements.
- Eliciting life cycle cost information from both the government and contractor project teams.
- Reviewing all assumptions and contractual change notices from the project teams and advising the programme manager of any points of issue.
- Providing guidance and assistance for the cost risk analysis and associated reports.
- Ensuring the smooth running and facilitation of the total life cycle cost management process, including the regular reporting procedures.

To achieve the above in the most practicable, auditable and robust manner it may be necessary to conduct the life cycle cost analysis using multiple methods and/or independent experts. This will depend on the overall value of the likely programme costs and the level of robustness needed for the government approval process.

2.8 TYPICAL APPLICATIONS OF LIFE CYCLE COSTING

One of the principal objectives of life cycle costing is to reduce or control the life cycle cost by assessing the financial impacts of the decisions taken about the complete system.

Three broad classes of applications rely on the output from life cycle costing and are discussed in detail below. These are:

- Determining the forecast of future spending.
- Examining comparisons between alternative solutions (e.g. alternative assets, design trade-off, supply chain analysis, etc.).
- Supporting the tender evaluation process.

In all cases, the output of the life cycle costing provides information to support the decision making process. Note however, that cost is just one of many criteria that could influence the decision. Other criteria such as operational effectiveness, technical risk, political and industrial policy constraints, etc., also have to be considered in the decision making process and are sometimes more important than cost.

2.8.1 Determine the Forecast of Future Spending – Defence Budget Planning Applications

Budget planners are often confronted with choices between several distinct systems (e.g. aircraft or UAV or missiles; ships or forward bases, etc.). The life cycle cost estimate can help the decision process by addressing the following typical questions:

- In consideration of long term planning applications (~10+ years):
  - What will be the cost of the systems currently being designed (both in terms of money spent annually and of the number of service personnel required to man the systems)?
  - What is the best ratio between money spent on investment (new systems or upgrades of ‘old ones’) and that spent in order to keep the readiness of currently available systems?
- In consideration of short term planning applications (~next 1 to 4 years):
  - How many systems (or individual platforms) can we afford (now) and still maintain some flexibility in future budgets (considering their estimated in-service costs)?

2.8.2 Examining Comparisons between Alternative Solutions

Comparative studies are particularly valuable in the early stages of planning when the primary objective is to establish an efficient and economical course of action. Comparative studies are, actually, used throughout all phases of a system’s life cycle; they are also used in selecting in-service options such as in-house or contractor support.

An analytical comparison of the operational effectiveness, suitability and life cycle cost of alternative programmes that satisfy established capability needs is referred to as AoA (Analysis of Alternatives). An AoA broadly examines multiple elements of programme alternatives including technical risk, design maturity and cost. AoAs are intended to:

- Illuminate the risk, uncertainty and the relative advantages and disadvantages of the alternatives being considered.
- Show the sensitivity of each alternative to possible changes in key assumptions.
- Help decision makers in determining whether or not any of the proposed alternatives offer sufficient operational and/or economic benefit to be worth the cost. As a general rule, the preferred alternative is the alternative that provides the greatest amount of benefits in relation to its cost.

2.8.3 Supporting the Tender Evaluation Process

In the tender evaluation process the life cycle costs can be used to ensure that the contract award is made to the tenderer who offers a system that meets all technical and availability requirements at minimum life cycle cost. The cost of investment in reducing maintenance resources and the cost of lifetime support will be weighed against the cost of investment in the overall system. The resulting life cycle cost will therefore be beneficial to the overall tender evaluation process.

To establish a cost-effective in-service phase it is essential to consider operating and maintenance issues at the same time as the procurement of the system. The life cycle cost from the evaluation process can often be used as a baseline for negotiation on contractor logistic support contracts.

The choice of a proper time period (system life) in the life cycle cost evaluation process must be considered. For example, many parameters can influence the selection of a well balanced time-period. Very often the total technical life of a system may not be the most appropriate time period for the life cycle cost evaluation. A shorter time-period takes more consideration of the initial acquisition costs, and a longer time-period takes more consideration of the recurrent ownership costs.

Figure 2-11 presents the life cycle costs for two competing systems A (green) and B (red). The initial acquisition price for System B is less expensive than for System A. However, System A has lower annual cost for ownership than System B. At year 10 the cost-lines intersect, and after year 10 System A has a lower life cycle cost compared to System B. The example shows the complexity of choosing the “correct” time period to include in a tender evaluation. This example clearly demonstrates that the selection of a life cycle time period must be tailored and well balanced to fit its purpose.

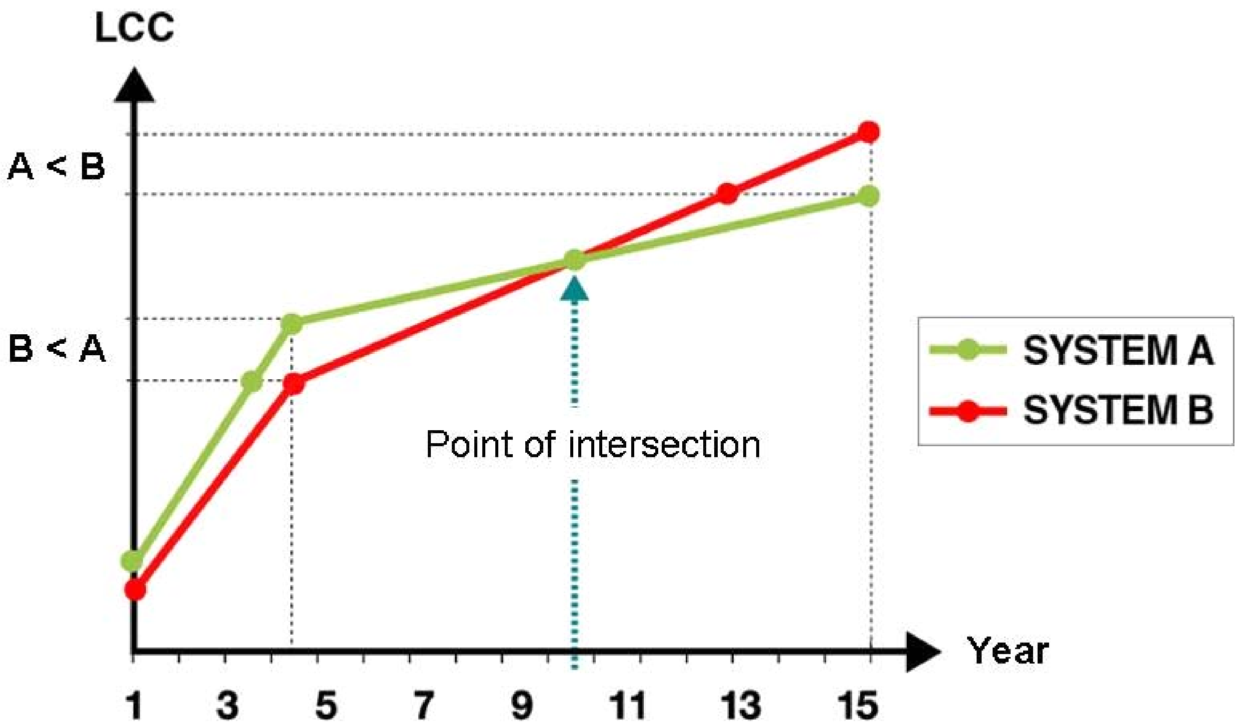


Figure 2-11: Example of Time-Period Consideration.

To ensure that all the tenders are impartially evaluated it is vital that the cost breakdown structure is defined by the procurement agency. This should include a definition of all the cost elements. Sufficient data on the likely use of the system should also be included in the request for quotation. This will improve the prospective supplier’s ability to independently assess and possibly improve their offer.

It is recommended that a life cycle cost questionnaire is issued with the request for quotation so that the procurement agency can conduct an independent comparative life cycle cost evaluation on all the tenders. This will improve the understanding of the tender offer and provide a degree of credibility in the life cycle cost results.

However, before the request for quotation is issued, it is important that all the preparatory work has been independently conducted and that the Key User Requirements are well balanced between functionality and likely costs.

A life cycle cost evaluation starts with the quality of the submitted tender data. In most cases it is necessary to iterate the process several times in order to obtain clarification and to explore opportunities for improvements. Figure 2-12 shows the tender evaluation process with specific feedback to the tenderers in order to exploit opportunities for cost reduction. The tender evaluation process is completed by documenting the LCC results in an evaluation report before the contract can be awarded.

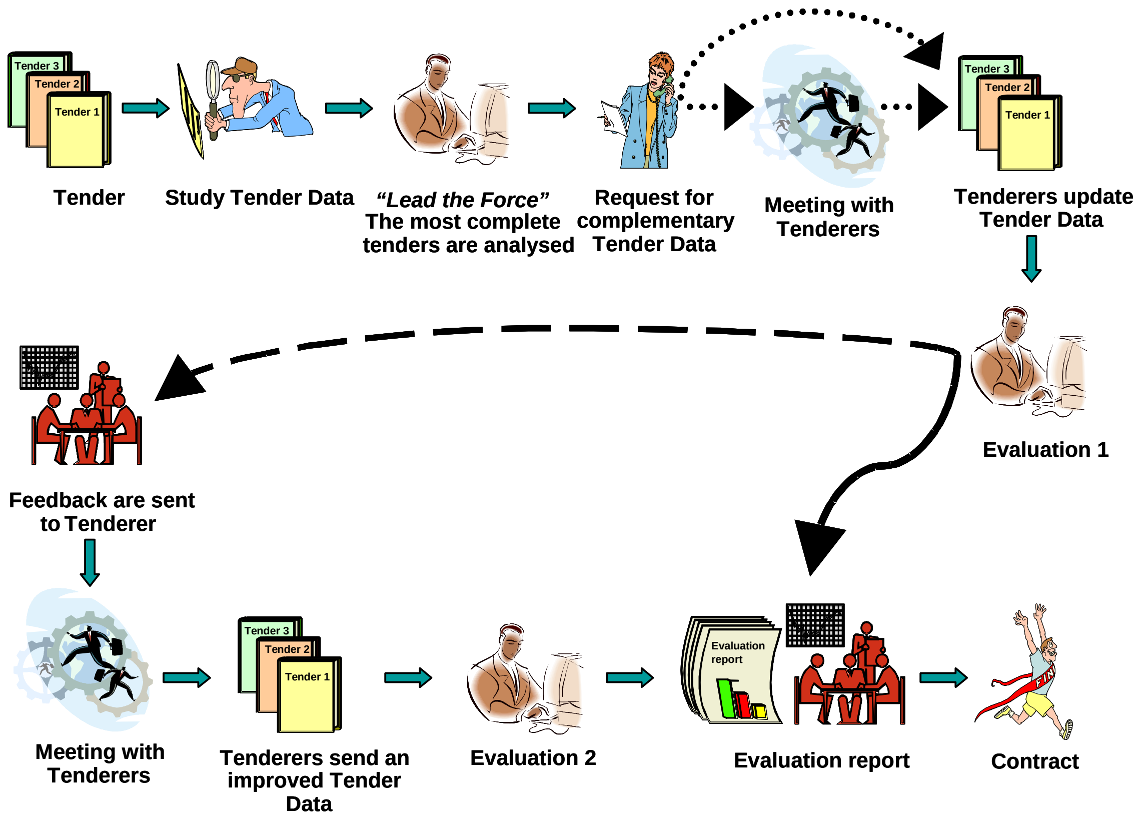


Figure 2-12: LCC and the Tender Evaluation Process.

2.9 ASSESSING AFFORDABILITY

This is not common practice in all nations, but it is one that we recommend should be conducted.

By definition, affordability can be considered as the degree to which the life cycle cost of an acquisition programme is **in consonance** with the long-range investment and force structure plans of national defence administrations. Affordability procedures establish the basis for fostering greater **programme stability** through the **assessment** of programme affordability and the **determination of affordability constraints**. In this context:

- **In consonance** means delivering systems that meet the customer's needs and budget.
- **Programme stability** means working towards sustainable opportunities.
- **Assessment** means creating a programme management strategy that guarantees programme viability.
- **Determination of affordability constraints** means bringing affordability to the foreground to avoid misconceptions in management and engineering which may ultimately lead to unaffordable design solutions.

Affordability plays an important part in programme decisions throughout the life-cycle. Even before a programme is formally approved for initiation, affordability plays a key role in the identification of capability needs. Programme affordability is part of the process which balances cost versus performance and in establishing key performance parameters.

The exact approach to the affordability assessment can vary, depending on the nature of the programme. However, in general, the assessment should address programme funding and manpower requirements over the whole life period. The assessment also should show how the projected funding and manpower fits within the overall plan for simultaneous programmes. The assessment should highlight those areas where the projected funding or manpower share exceeds historical averages, or where the projected funding or manpower exceeds zero real growth from the last year of the programming period. For the issues highlighted, the assessment should provide details as to how excess funding or manpower demands will be accommodated by reductions in other mission areas, or in other (e.g. non-modernisation) accounts. To illustrate this approach, this section provides a notional example of the type of analyses that could be incorporated in an affordability assessment. Although this example only addresses modernisation funding, the approach for manpower would be similar.

In this hypothetical example, a major defence acquisition programme is nearing government approval. For discussion purposes, this programme arbitrarily is assumed to be a mobility programme. A first step in the programmes affordability assessment is to portray the projected annual modernisation funding (Research, Development, Test and Evaluation plus procurement, measured as total authority obligation) in constant dollars for the six-year programming period, and, in addition, for an additional twelve years beyond that. Similar funding streams for other acquisition programmes in the same mission area (in this example, mobility) also would be included. Figure 2-13 is a sample chart for this first step.

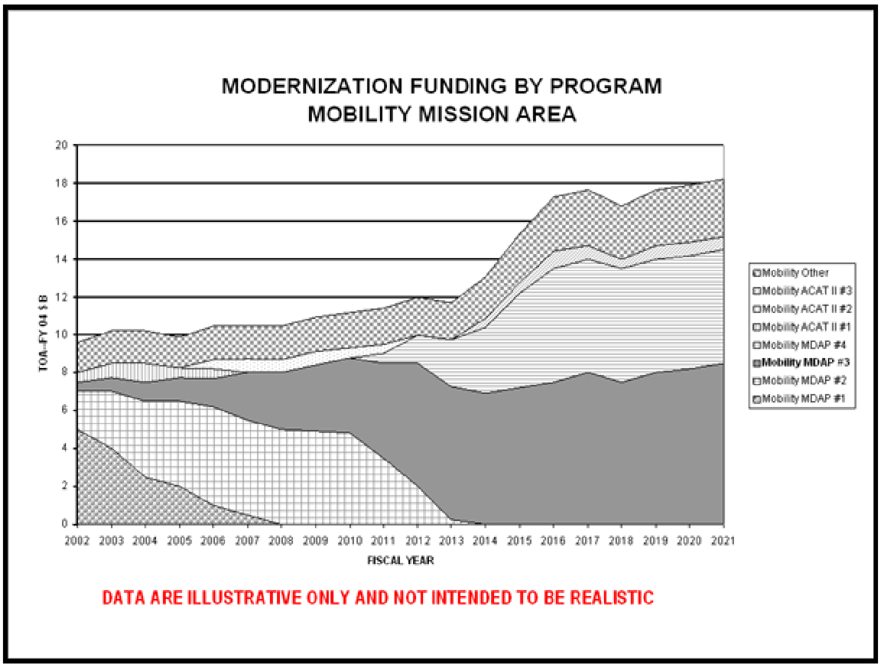


Figure 2-13: Sample Chart of Funding Streams by Programme.

In this example, the acquisition programme nearing approval is labelled “Mobility MDAP #3.” Funding also is shown for the other modernisation programmes in the same mission area, consisting of three other major defence acquisition programmes, three other (Acquisition Category II) programmes, and one miscellaneous category for minor procurement. In this example, there appears to be a significant

modernisation bow wave beginning around 2014, which would then be subject to further analysis and discussion in the assessment. The term “bow wave” refers to a requirement for excess modernisation funds during a period beyond the programming period, resulting from acquisition decisions made earlier.

The second step in this assessment is to portray the modernisation funding stratified by mission areas, rather than by individual programmes. Figure 2-14 shows a notional example of this second step. The choice of mission areas will vary depending upon circumstances. Clearly, an analysis by an individual Component[6] would portray funding only for applicable mission areas. Also, for a Component like the Army, where almost all of its modernisation funding is in a single mission area (Land Forces), the mission area should be further divided into more specialised categories (such as digitisation, helicopters, ground combat vehicles, etc.).

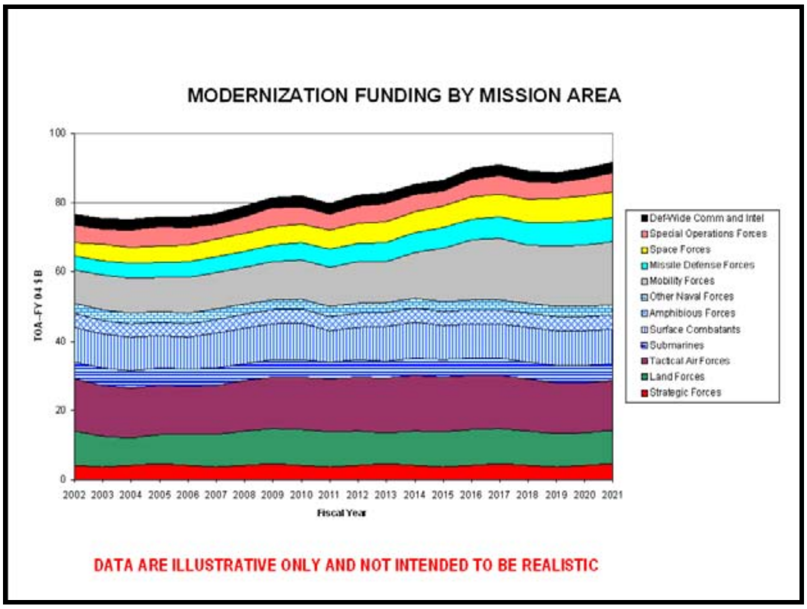


Figure 2-14: Sample Chart of Funding Streams by Mission Area.

For this example, Figure 2-14 shows funding growth in three mission areas (space, missile defence, and mobility). What remains to be determined is whether this projected growth is realistically affordable relative to the Department’s Component’s most likely overall funding (top-line). The third step in this assessment is to portray annual modernisation funding compared to the Department’s Component actual or projected funding top-line, as shown in Figure 2-15. There are three distinct time periods considered in this figure. The first is a twelve-year historical period, the second is the six-year programming period, and the third is the twelve-year projection beyond the programming period. What this chart shows for this example is that the assumed mobility programmes are projected to require a significantly higher share of the Department’s Component funding in the years beyond the programming period. In such a circumstance, the Department’s Component would be expected to rationalise or justify this projected funding growth as realistic (by identifying offsets in modernisation for other lower priority mission areas, or perhaps by identifying savings in other accounts due to business process improvements or reforms).

[6] A “Component” is a military department or a defence agency.

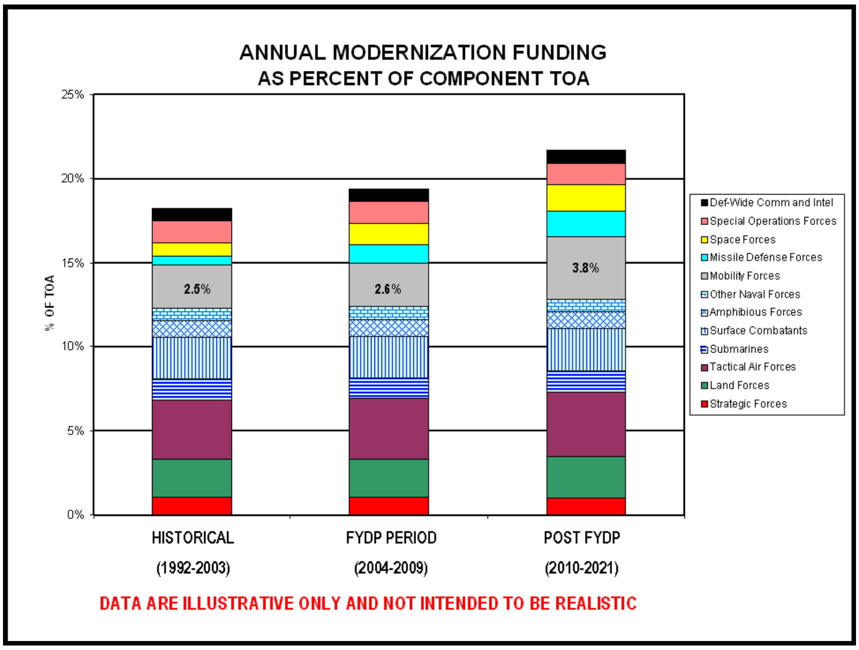


Figure 2-15: Sample Annual Modernisation Funding.

2.10 SPECIAL REQUIREMENTS FOR MULTI-NATIONAL PROGRAMMES

The life cycle cost studies for multi-national programmes follow the same principles as defined in the previous sub-sections. Nevertheless, there are some specifics that should be taken into account in terms of organisation, studies, model(s) and in the presentation of the results.

2.10.1 Definitions

Multi-national programmes involve at least two nations who have agreed upon the main principles of co-operation in a MoU (memorandum of understanding), or an equivalent arrangement, for one or several phases of the entire lifetime of that programme.

2.10.2 Specifics of Multi-National Programmes

2.10.2.1 Framework

A programme becomes multi-national as soon as a MoU is agreed and signed between the participants. In the NATO environment, it is assumed that such a MoU would normally start with the feasibility phase, at the earliest[7]. This means that the life cycle cost studies undertaken during the first phases (Mission Need Evaluation and Pre-Feasibility phases at least) are done at a national level.

2.10.2.2 Added Value

A significant added value of a multi-national programme is the possibility of setting up common solutions for procurement and support. This results in reduced life cycle cost due to research for greater commonality across the participants.

[7] Reference AACP-1 Allied Acquisition Practices Publications.

Another mutual benefit of a NATO collaborative programme is the economic saving that accrues due to cost sharing. In a NATO collaborative programme, the principal area of cost sharing occurs in the common non-recurring cost elements and the operation of the international programme office. Cost shares may be determined or allocated to the participating nations in a number of ways (e.g. costs may be allocated based on quantities procured during production, capital outlay of the respective nations, or other agreed means).

The co-operation of several nations within a multi-national programme may result in higher absolute costs – due to additional expenses for travel, accommodation, communication, information exchange, standardisation agreements, approval of procedures, etc., than the case of a national programme. Nevertheless, when sharing this higher total amount, the share per nation will usually be lower than for the same cost elements of a national programme thus resulting in overall programme savings from a national perspective. Some of these initial additional efforts such as developing a common methodological approach, standardisation agreements, etc., may be incurred only once and then be made available to future programmes at minimal additional cost.

2.10.2.3 Taking into Account “juste retour” (Fair Return on Investment)

Although common solutions reduce an overall life cycle cost, it is obvious that the participants will require a balance of financial and technological demands against the industrial benefit that flow from the programme (“juste retour” or fair return). This last requirement (industrial benefit) should also be taken into account in the life cycle cost studies.

This consideration implies the definition of a work sharing methodology to be utilised in future NATO programme cost estimating applications. The methodology requires an equitable distribution of work share for engineering, manufacturing and service related activity across the participating nations according to the capital outlay of the respective nations or as they otherwise may agree. The goal is to achieve an overall sharing balance through an optimum mix of development and management work, centrally procured major equipment, domestically procured miscellaneous material, land based facilities, and national construction activity. Additionally, offsets may be necessary in some cases and cost-effectiveness must be considered.

An objective evaluation is necessary to determine the optimum mix (technical requirements met and cost-effectiveness within work sharing constraints) of centrally procured equipment. This process involves assessing bids from participating national industries to establish an optimal distribution based on technical, cost, and work sharing considerations. Due to the large number of possible combinations, a computer assisted evaluation model is helpful if not essential.

2.10.3 Organisation

2.10.3.1 Multi-National Management Structure Models

There are basically three models for setting up a management structure for multi-national programmes in a NATO environment. These are:

- **The pilot nation model**, where the responsibilities for the day-to-day management of the programme, under the direction of a joint steering committee are exercised by one of the participants on behalf of all.
- **The integrated model**, where day-to-day management of the programme is secured either by an IPO (international programme office) under the authority of a joint steering committee or by an executive agency of a NATO organisation under the authority of a board of directors, having international status as a legal entity under a NATO charter in accordance with C-M(62)18[8].

[8] C-M(62)18 is related to the NATO council resolution on regulations for NATO production and logistic organisation.

- **The decentralised model**, where the joint steering committee has minimum power of decision, serving mainly as a medium for co-ordination and information.

2.10.3.2 Consequences on Life Cycle Costing Organisation

In the case of the first and second models of multi-national management structures, the pilot nation or the IPO or the NATO agency could be responsible for the life cycle cost estimates and comparison of alternatives within a scope to be defined by the participants (see Sub-section 2.10.4). One or more participant(s) could perform a peer review including a verification and validation of the life cycle cost studies performed above. The basic principle is that these studies should be based on an agreed common life cycle cost model (see Sub-section 2.10.6).

In the case of the third organisational model of multi-national management structure, the participants could agree on choosing one of them for the performance of the life cycle cost studies. Therefore the same organisation scheme as described above could be applied.

2.10.4 Scope of the LCC Studies in Multi-National Programmes

There are two main parts in undertaking life cycle cost studies for multi-national programmes. These are:

- Life cycle costing related to national specifics. For example, government furnished equipment acquisition, national programme management team.
- Life cycle costing related to the development of commonality part where different alternatives have to be compared and evaluated.

The first part is mainly a national responsibility. Nevertheless, if the participants want the pilot nation or the IPO or the NATO agency to perform a complete study, then the outputs of the life cycle cost relating to the national specifics should be inserted into the common model.

The second part is in the scope of the life cycle costing studies in multi-national programmes. Here it is necessary to identify the areas in which alternatives could be defined and assessed. Figure 2-16 below shows a process for the selection of the areas and the definition of the related scenario.

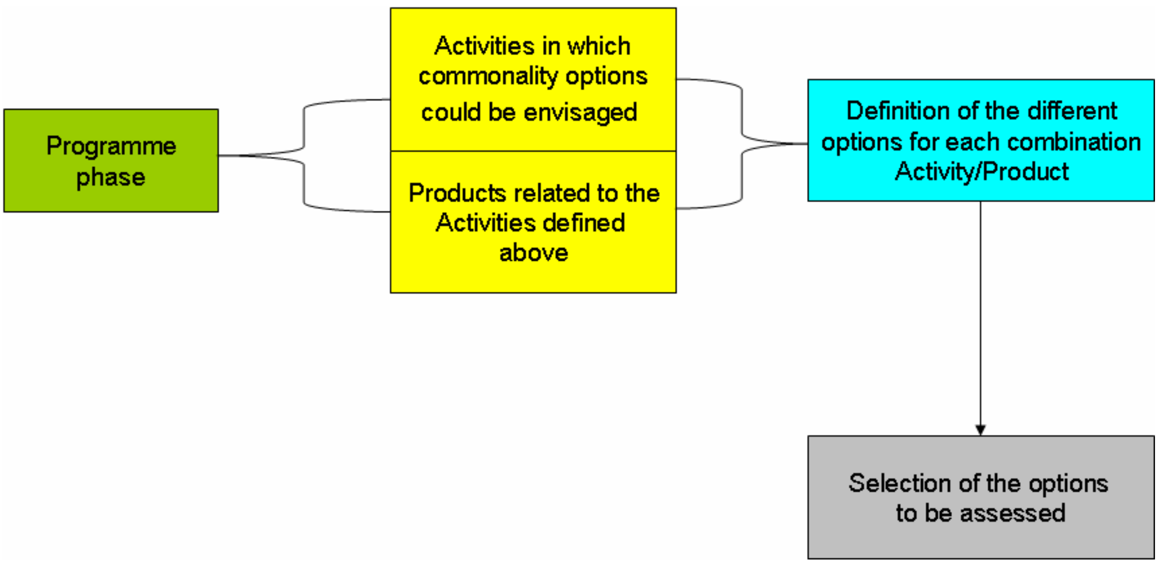


Figure 2-16: Identification of the Options to be Assessed.

2.10.5 Example

The different options to be considered could therefore relate to the management of support during the in-service phase particularly over the maintenance activities and of the support equipment. The life cycle costs would therefore have to consider the effects of the following activities:

- Common maintenance by participant nations.
- National maintenance on behalf of other nations.
- Common contractor logistic support.
- NATO maintenance.
- National maintenance.

Based on the results from the life cycle costing the selection of the options to be pursued would be based on the respective savings, opportunities, operational policy, etc.

2.10.6 Setting up a Common Life Cycle Cost Framework

Setting-up a common life cycle cost framework includes the following steps:

Step 1: The selection of the different models that will be used in common for the programme;

Step 2: The definition of the Programme Cost Breakdown Structure (CBS) and the way of aggregating the results of the different models into one framework;

Step 3: The definition of the assumptions to be applied for the LCC calculation and to be used for data collection; and

Step 4: The collection of the data.

Step 1: Selection of Common Life Cycle Cost Models

All interested parties in the life cycle cost calculation have to agree on the use of common models. This will ensure that all subsequent calculations can be compared on an equal basis. The models should be either programme specific or COTS (commercial off the shelf), as required by the need of the programme. The functionalities of such models must allow an easy interface with those models eventually defined at a national level.

Step 2: Definition of a Common Cost Breakdown Structure and Output Aggregation

Together with the selection of the models, a common CBS (cost breakdown structure) must be defined for the programme. This CBS should be based on the NATO generic cost breakdown structure (Reference: RTO-TR-058 report). It should also allow the insertion of the cost elements relating to national specifics if required (see Sub-section 2.10.4).

The results from the different models selected in step one should be aggregated following the CBS defined above. Figure 2-17 shows this aggregation.

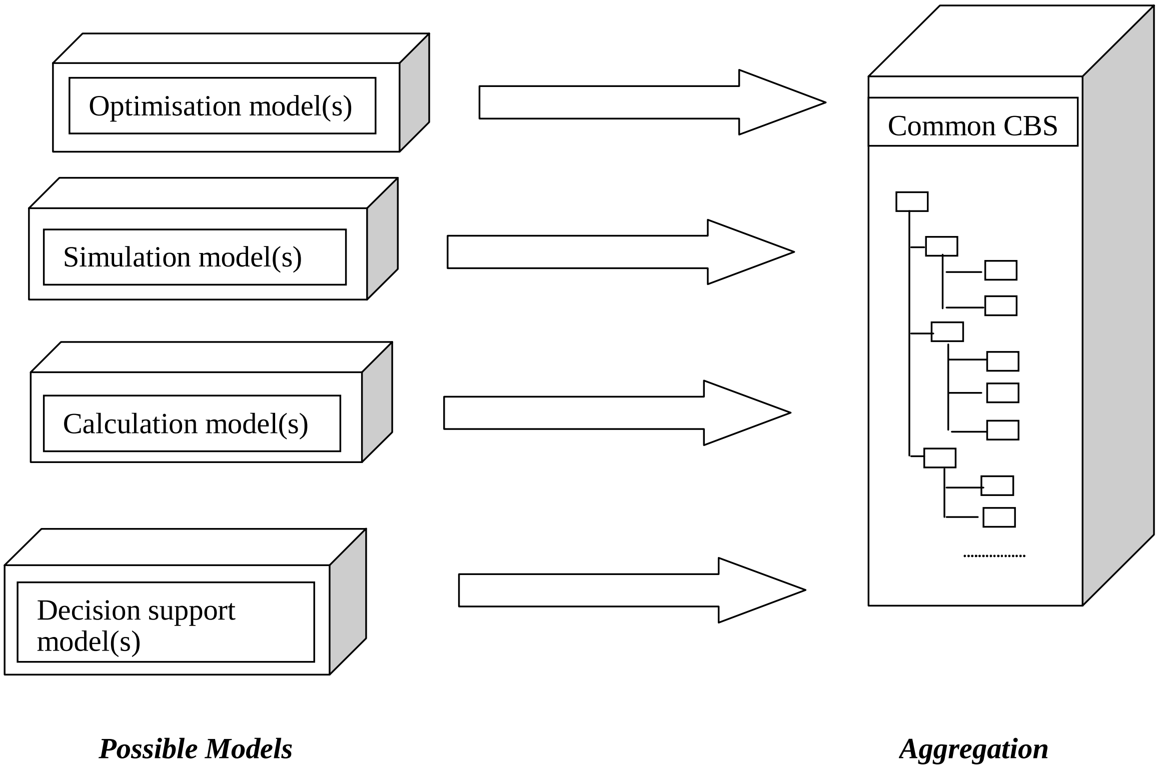


Figure 2-17: Models Output Aggregation.

Step 3: Assumptions (see also Sub-section 2.3.2)

Once the models (with the way of aggregating their outputs) and CBS have been defined, the assumptions necessary to define the cost data should be commonly determined and agreed. The pilot nation or IPO or NATO agency should build an MDAL or CARD or equivalent where all the assumptions necessary to the definition of the cost elements are included. It is acceptable (and in some instances, inevitable), that different nations will use different assumptions. This should, however, be reflected in the MDAL, CARD or equivalent document.

Great care must be particularly applied to the assumptions of deployment. It is likely that each nation may have slightly different deployment and supportability considerations than are usually reflected in the memorandum of understanding or similar arrangements. These should be taken into account in the MDAL, CARD or equivalent document while a consensus for a multi-national scenario is to be defined. In this way, optimised solutions can be evaluated to address both national and multi-national concerns.

Step 4: Data Collection (see also Sub-section 2.3.4)

Based on the agreed CBS and MDAL, CARD or equivalent, the data required to feed the models will have to be collected. The source of that data can vary between programmes, but it will generally include participating nations, industry and the pilot nation or IPO or NATO agency.

2.10.7 Presentation of the Results: Currency Issues

Generally, the cost data utilised as input to a multi-national programme is initially specified in the currency of the supplier nation. For non-domestic work and items subject to international influence of the participating nations, exchange rates between the national currencies are utilised as the currency conversion mechanism to

develop national cost estimates. Application of escalation formulae using indices from the supplier nation allows for changes due to national inflation prior to conversion to other currencies.

With the advent of the European Union, more and more nations have adopted the Euro instead of their former national currencies and the Euro has become the reference currency for expression of multi-national cost estimates and cost targets. Such a reference currency may be useful for performing design trade-offs or pricing the average cost for comparison against an established cost target.

Some past programmes have utilised Purchasing Power Parities (PPP) as the currency exchange mechanism for domestic work under the direct control of the respective nations, e.g. labour. PPP are rates of currency conversion that equalise the purchasing power of the different national currencies. Variations in PPP over time are mainly governed by the difference of inflation rates between countries. PPP vary slowly in contrast to currency exchange rates that are subject to market stresses. PPP may be useful when comparing costs between specific nations and may provide insight useful to planning purposes of the respective nations or for trend forecasting associated with NATO collaborative programme cost estimates.

Despite the need for a reference currency and the issues of currency exchange that must be agreed upon, ***it is recommended that each nation apply its own cost model and applicable data (Cost Estimating Relationships, labour rates, etc.) to arrive at its national cost estimate.***

The choice of the currency should be made before the launch of the life cycle cost studies and the evolution of the exchange rates taken into account in the model. ***It is highly recommended that the life cycle cost analyst seeks economic advice that is pertinent to the particular programme to be evaluated.***

See also Sub-section 6.5.4 for more details on exchange rates and currency issues.

Chapter 3 – LIFE CYCLE COSTING IN THE PAPS PHASES

3.1 GENERAL

Most nations use their own standards and nomenclature for describing the life cycle of a project. In multi-national projects and documents for use in various national and multi-national contexts, a common standard is needed. The Phased Armaments Programming System (PAPS) provides such a common standard, approved and accepted by NATO nations. For this reason, the PAPS definitions of the life cycle phases have been adopted in this report. Accordingly, this chapter is structured along the lines of PAPS.

A short introduction to PAPS is given below, and the PAPS phases are described in Section 3.2. The following sections describe the method and application of life cycle costing techniques that are appropriate to each of the PAPS phases. Note that Section 3.6 is devoted to programmes where a system is bought rather than designed and built.

For consistency, each section covers:

- A summary definition of the phase as given in PAPS.
- The life cycle costing inputs and outputs expected from that particular phase.
- An illustration of the benefits that life cycle costing studies can bring in this phase.
- The types of life cycle cost analysis that can be conducted in this phase.
- The life cycle costing methods that can be employed in this phase.
- An example to illustrate the use of life cycle costing in this phase.
- The process to be followed for conducting life cycle costing in this phase.
- A method for assessing risk at this phase.
- References where further information can be obtained.

The PAPS life cycle phase definitions are used in this report because they constitute an internationally approved standard. National and other standards differ from these, however. In order to find the section(s) in this chapter relevant to a given phase in a project or programme using different terms and definitions, it is therefore necessary for the reader to first “translate” these to the equivalent PAPS phases.

For the nations contributing to this study, the relationship between national standards and PAPS are already provided in the information matrices shown in Annex A. Furthermore, an international standard for dividing the life cycle into stages exists, defined in the international standard for system life cycle processes, ISO 15288. A short description of this, including a description of the relationship between the PAPS life cycle phases and the ISO 15288 life cycle stages, is provided in Section 3.10 of this chapter. These may also serve as inspiration to readers using other standards.

3.1.1 Make or Buy

The PAPS covers the life cycle of a programme from identification of a need for a new capability through specifications, design, production, use and eventual retirement of the system. It is general enough to cover most national and other life cycle models for this type of programme. However, in many defence organisations, particularly in smaller nations, the typical life cycle of weapons systems and other materiel systems is substantially different, because systems are bought rather than designed and built. This has wide implications for the whole life cycle management process, including life cycle costing, especially in some of the earlier phases of a programme.

In essence, buying a system involves a choice between relatively few, clearly defined and well described and documented alternatives, informed through a process of market research. In contrast, designing and building a system from scratch means choosing a solution from a practically infinite number of possibilities through a process of design, development, and manufacture. These differences have important implications for life cycle costing with regard to the process and method to be followed, the data available and the desired results.

Hence, the difference of a “buy” programme from a “make” programme as described in PAPS is so great that it warrants a special treatment. This is given in Sub-section 3.2.9 which covers the decision between building or buying a system, and introduces an alternative “procurement” phase to replace the “design & development and production phases” in the case where the decision has been made to buy a system. Section 3.6 covers life cycle costing in this alternative “procurement phase”.

3.1.2 PAPS Background

The handbook on PAPS was published in February 1989 as AAP-20 (Allied Administrative Publication) by Defence Support Division of NATO International Staff.

The stated overall objective of PAPS is “to provide a systematic and coherent, yet flexible, framework for promoting co-operative programmes on the basis of harmonised military requirements”. It is further stated: “The philosophy behind the PAPS concept is straight forward”.

There is a finite and fairly consistent number of points (milestones) in the life of a weapon system programme when the nature of the programme changes. At these milestones, decisions must be made regarding alternative courses of action. PAPS is intended to provide a structured approach to aid decision-making at these milestones for all management levels involved in co-operative Research & Development and production programmes within NATO.

PAPS is primarily intended for use in a multi-national weapon system procurement programme in a NATO framework, involving two or more nations working together to fill a common capability gap. However, the principles laid down in PAPS are applicable to national programmes as well, especially since it is repeatedly emphasised that PAPS should in any case be adapted to the conditions of the individual project.

Though the main focus is on the milestones, PAPS also describes the phases between the milestones, thus dividing the life cycle of a system into separate well defined phases. An overview of these phases and the milestones that separate them is provided in Figure 3-1, short descriptions of the phases are provided in Section 3.2, while descriptions of the milestone definitions are found in Annex E.

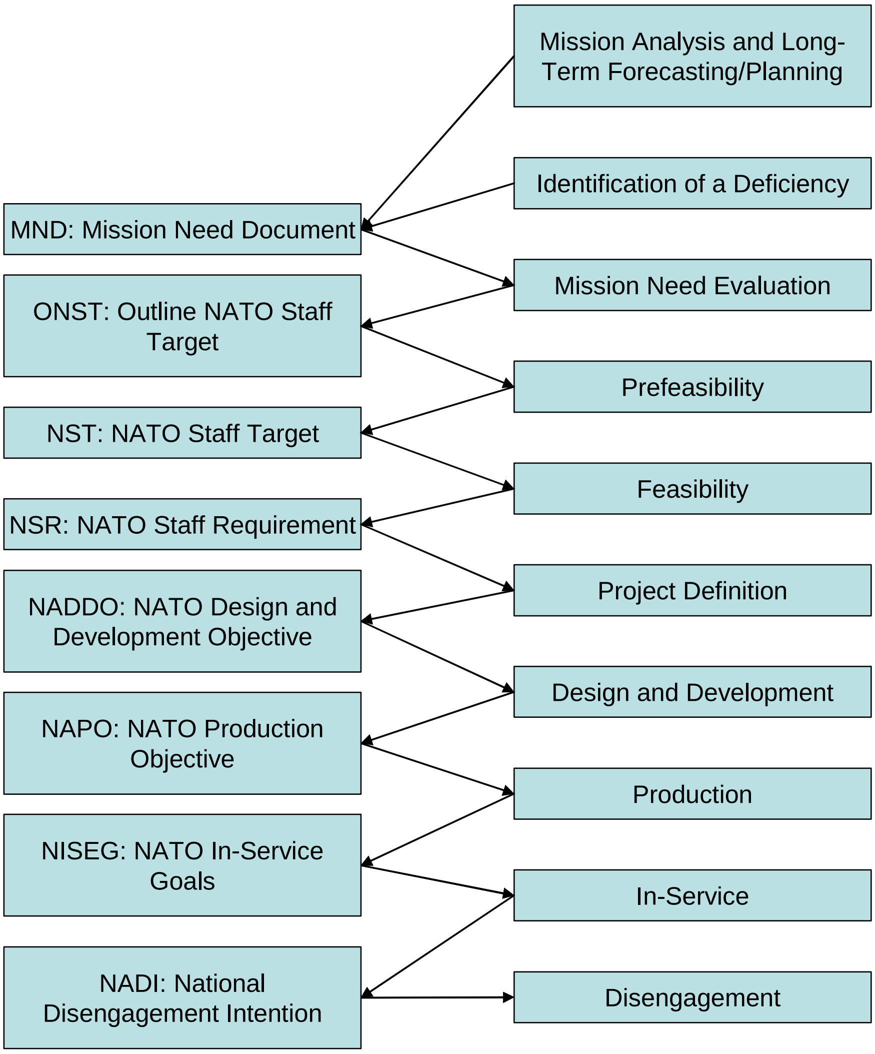


Figure 3-1: PAPS Life Cycle Milestones and Phases.

3.2 PAPS PHASES

The following descriptions of the life cycle phases have been drawn directly from AAP-20.

3.2.1 Mission Need Evaluation Phase

A statement based on a mission analysis, identifying in broad outline a quantitative or qualitative operational deficiency that cannot be solved satisfactorily with existing or planned forces and/or equipment.

3.2.2 Pre-Feasibility Phase

The work in this phase will determine whether or not the Outline NATO Staff Target merits a deeper feasibility study. It is conducted either by industry and/or government agencies, or by NIAG (NATO Industrial Advisory Group). Its aim is to examine the proposal, assess the trade-off points and make a broad assessment of the practicable alternatives and also the penalties involved in adopting certain courses of action. This study should establish the feasibility of suitable solutions consistent with the timetable of needs. The pre-feasibility study will result in the establishment of a NATO Staff Target.

3.2.3 Feasibility Phase

A feasibility study is carried out by industry or government agencies or a combination of both with the object of providing a technical appraisal of the feasibility of developing and producing an equipment with the performance required by the NATO Staff Target. The study identifies areas of technical risk, recommends characteristics of the system(s) and gives the optimum balance between performance, cost and development time. The study also indicates areas where considerable advances on the existing state of knowledge are likely to prove necessary for successful development. It also indicates the means by which the recommended solution will be achieved, suggests a programme for project definition, development and production, with a preliminary estimate of the costs for these stages. The feasibility study must result in the establishment of a NATO Staff Requirement.

3.2.4 Project Definition Phase

This is the process of thoroughly exploring all aspects of the proposed project and to examine the relationships between the required performance, development time and cost. The areas of technical uncertainty are examined and possible trade-offs are evolved in order to achieve a satisfactory balance between performance, development time and cost. These trade-offs may lead to amending the operational requirement. From then on, performance requirements and detailed requirements regarding the technical characteristics are established so as to meet the operational requirement under the best conditions.

These requirements will form the basis of the establishment of a development programme and of more detailed and realistic estimates of development time and cost. The overall results of the studies carried out during project definition will be used for the discussion on whether to proceed with the development or not.

3.2.5 Design and Development Phase

This phase of a programme calls for design engineering work aimed at full validation of the technical approach and ensures complete system integration to the point where production contract action can be taken.

The design and development phase embraces all activities from the preparation of the development contract to the approval of the equipment as ready for introduction into service. During the course of this phase, the configuration of the equipment is gradually improved. Factory trials are carried out to evaluate the results of the design and development activities as far as technology and economics are concerned.

The engineering work comprises prototype production and technical evaluation trials to determine the technical capability of the complete system. The subsequent user trial is designed to test the material under realistic conditions. The criteria are tactical mission, military requirements and easy maintenance and repair.

At the end of the phase, the design status for the manufacture of the equipment is determined on the basis of statements about technical readiness and field operability.

A unanimous agreement is required in the steering committee on all provisions, especially operational characteristics, financial commitments, agencies involved, follow-on measures, and industrial involvement.

3.2.6 Production Phase

The production phase has been defined as: the manufacture of a system, sub-system or equipment in a plant or factory using series (i.e. full-scale) manufacturing techniques.

The production phase embraces all measures taken to initiate and carry out series production of equipment in accordance with the operational requirements and the final development specification up to delivery to depots or unit stores. At the beginning of the phase a production contract will be concluded by the management office, established by the NPSC (NATO Project Steering Committee).

By this stage, a statement should be obtained from the Steering Committee on the logistics support and training arrangements for the equipment. Whenever possible and appropriate, common logistics support (including the option of the NAMSA (NATO Maintenance and Supply Agency) and/or training arrangements should be established.

During this phase several activities aiming at full logistics supportability have to be pursued by the management office, such as:

- Production Control.
- Quality Control.
- Acceptance Trial.
- Codification.
- Configuration Control.
- Modification Trials.

3.2.7 In-Service Phase

This is defined as the operational utilisation of equipment by nations. The in-service phase embraces the totality of activities aimed at maintaining or restoring full serviceability of the equipment. It includes procedures and trials concerning introduction of modifications.

3.2.8 Disengagement Phase

This phase encompasses the withdrawal of equipment from operational utilisation in accordance with the NADI (National Disengagement Intention).

3.2.9 Alternative Procurement Phase (Make or Buy Decision)

The NATO PAPS phases describe the process to be followed in developing and procuring a new system in order to fulfil a capability gap. However, at some point in the NATO life cycle the decision has to be made either to develop a new system or to procure an off-the-shelf new system. In practice, this would be one of the options to be considered. Figure 3-2 shows that in the case of a traditional development programme (make track) all the NATO life cycle phases can be followed. Alternatively, in the case of acquiring a new system (buy track) some phases from the NATO life cycle will be replaced by a procurement phase to allow for a direct acquisition. The figure provides a simplified overview of the PAPS NATO life cycle phases for a make or a buy decision. It is always possible to go to a procurement phase from any phase in the PAPS process. However, the most suitable moment to decide on a buy decision would be after the project definition phase.

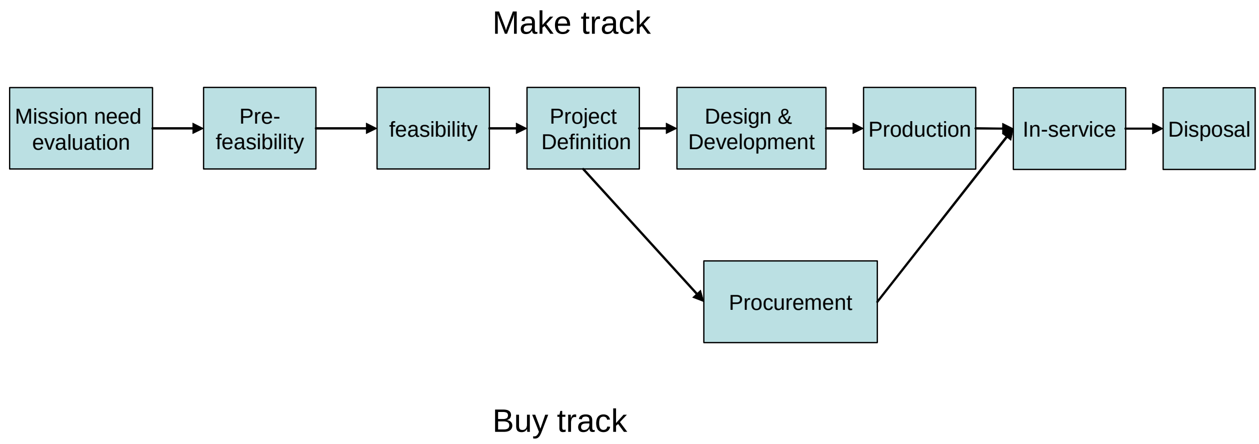


Figure 3-2: Make or Buy Track PAPS Life Cycle.

A procurement phase may replace the design & development and the production phase. A more detailed description of this phase can be found in Section 3.6.

3.3 MISSION NEED AND PRE-FEASIBILITY PHASE

3.3.1 Summary Definition of Phase

This phase is to determine the operational capabilities of military forces that are required to carry out assigned missions, roles and tasks. A comparative assessment is conducted to identify any deficiencies that may be related to the element of risk required. This process is then followed by a pre-feasibility study to examine the practicable alternatives and establish the feasibility of suitable solutions consistent with the time-table of needs.

The pre-feasibility phase is arguably the most important phase in a programme. It is where decisions are made when the amount of supporting information is at a minimum.

3.3.2 Inputs

Equipment programmes come into existence as a result of work to identify capability gaps[1]. These studies address the extent of the capability gap, the numbers of equipment or types of platforms required and the technologies that can help to fill the gap. A capability gap will trigger the requirement to conduct a balance of investment to consider a 'strategic fit' in a wider context. Several options will be included here including a 'Do Nothing' or 'Do Minimum' options on legacy systems as well as conducting a thorough evaluation on the benefits of procuring new and novel systems. At this phase in the life cycle it is unlikely that the costs can be identified in a great deal of detail, rather an understanding of the total programme costs and the uncertainty surrounding these estimates is required.

Since cost and performance data are likely to be immature care should be taken to avoid new conceptual proposals being given unwarranted advantage in comparison with those that have been more thoroughly explored. For this reason, the processes employed to support and undertake the balance of investment normally embrace the following:

[1] NATO Capability Based Planning: SAS-057, SAS-063 and AC/327 SG b WG 1.

- Qualitative approaches that exploit the judgement of military and technology subject matter experts who will draw on operational evidence and technology application opportunities.
- Quantitative approaches that will employ mathematical modelling of physical system behaviour (principal measurable attributes) within the context of representative operational or business situations.

To support the activities above, a systematic, rigorous and auditable process needs to be adopted. This process will be supported by the Outline NATO Staff Target document and an outline CONOPS (Concept of Operation) statement from the NATO project steering committee. Cost models that provide a holistic (e.g. whole) estimate of cost and time are essential for this phase. The cost models should also provide the estimates with defined confidence levels and have the ability to provide a 'what if' capability.

3.3.3 Outputs

The outputs from this phase should indicate which of the options are feasible and affordable (see also Section 2.9) and should be taken forward for further study. The life cycle cost estimates should support the refinement of the NATO Staff Target.

3.3.4 Life Cycle Cost Benefits

Life cycle costing at this phase is conducted at a very high level and is used to demonstrate the relationships between performance (e.g. fleet mix/sizes), procurement policy and life cycle costs. This will ensure that all the issues associated with the alternative solutions are considered and evaluated on a through life basis.

3.3.5 Types of Life Cycle Cost Studies

The types of costing studies being conducted at this phase are predominantly restricted to high-level balance of investment, cost benefit analysis and cost-effectiveness studies utilising the life cycle cost as one of the measures. Typical examples of these applications are given at Sub-section 3.3.9. All these studies are usually supported by Operational Analysis to establish needs and numbers and performance measurement criteria.

3.3.6 Methods Employed

The life cycle cost estimates derived during this phase usually employ Bayesian, Parametric, Analogous, Expert Opinion, or Rule of Thumb techniques. A description of these methods is given at Chapter 4. These methods are well established and can provide a holistic estimate to meet the requirements of the study. However, care should be exercised when considering an analogous approach. To avoid error, it is essential that all comparison using analogy is conducted on a 'like for like' basis. Therefore some normalisation of the source platform/system/equipment is likely to be required. As in this phase only limited quantitative information will be available, also decision support methods or simulation methods like system dynamics can be used.

3.3.7 Life Cycle Costing Process

Figure 3-3 provides a simple illustration of the life cycle costing process. It shows that at this PAPS phase the source data to support the life cycle costing is likely to be immature. Therefore a greater reliance on the types of data sources indicated should be expected. In addition, there will be a high level of assumptions in terms of the likely performance/design parameters of the systems being evaluated. Risk is likely to be measured in a more qualitative rather than quantitative manner.

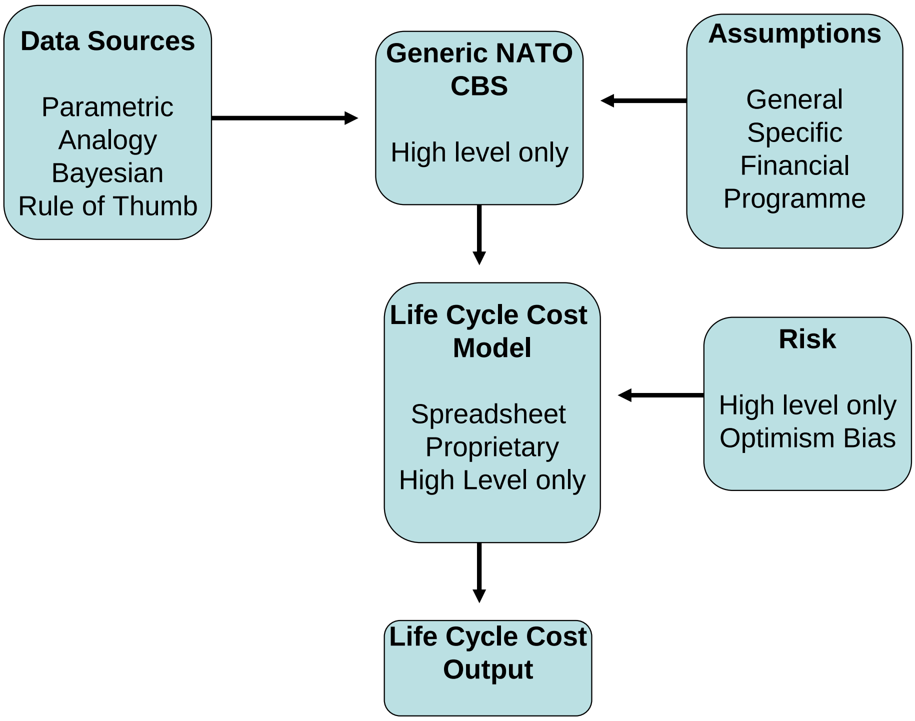


Figure 3-3: Simplified Pre-Feasibility Phase Life Cycle Costing Process.

It should be expected therefore that the life cycle cost output will be an understanding of the total programme costs and the level of uncertainty surrounding them. In summary, the key considerations to the life cycle costing process for this phase are:

- The principal data sources are likely to be parametric based and for speed and ease of use a commercially available cost estimating model is likely to be employed.
- There will be many ground rules and assumptions to be recorded and assessed.
- The risk will be measured at the very top level probably utilising some high level risk register or optimism bias technique (a detailed description on risk analysis is given at Chapter 7).
- The life cycle costs are likely to be reported at the principal cost element level of the generic NATO CBS only as shown in Figure 10-1, but probably analysed at a slightly lower level of granularity.

3.3.8 Risk Assessment

During this phase the identification of risk will be conducted at a very high level. It is likely to be a combination of single line statements and will probably contain a mixture of issues as well as risks. The cost analyst will need to distinguish the difference between them in order to ensure that only the relevant applicable risks are to be included in the cost estimate.

Where there is no risk register or risk record, an optimism bias technique can be employed. Here it could be used to redress over optimistic tendencies by making empirically based adjustments to the cost estimates (this technique is explained at Appendix A to Chapter 7).

At the very minimum, the life cycle cost estimate produced at this phase should include or indicate the level of financial risk exposure.

3.3.9 Examples

The following sub-sections demonstrate three alternative applications that are traditionally employed at this phase. These are: Balance of Investment, Cost Benefit Analysis and Cost-Effectiveness assessment.

All the cost estimates for the examples shown were conducted using a Bayesian estimating approach. This approach was adopted because:

- No suitable analogies were available without substantial data normalisation thus introducing a large uncertainty into the source data to be used for generating the CERs.
- No design data was available to establish nominal or realistic historical based CERs.

The utility of this approach may be illustrated further by considering the evolution of a programme. At its earliest stages, prior to any design or development work, estimates of design characteristics supplied by the estimator cannot be anything but imprecise. Through the Bayesian approach, the technique will then rely upon the (more certain) design norms, which it generates. As design and development proceed more certain information will become available to the estimator for input and estimates will be based progressively more upon such data. When design and development are complete design characteristics will be known exactly. Further details and an example on the technique are given at Chapter 4.

To complete the studies the life cycle cost estimates were linked to a decision support tool to provide a two dimensional view of the options being evaluated.

3.3.9.1 Balance of Investment

Balance of Investment studies traditionally employ portfolio analysis techniques and are used extensively in industry and commerce to analyse component business units of a particular portfolio of activities. The approach uses a technique, here called Factor Weighting Analysis (FWA), in order to allow the user to compare the key characteristics of each activity in comparison with other activities at the same level.

Portfolio Analysis has been very widely used in North America and Europe particularly in the private sector. Considerable research has been carried out to determine how it should be best employed and what benefits it confers to the user. Generally speaking, it is now an established part of strategic planning and management in the pharmaceutical and other high research industries. This technique is now being tested and used to evaluate and support investment strategies for defence portfolios.

Figure 3-4 shows an example of the results of a portfolio analysis. The diagram shows the estimated military value and risk of a group of weapon systems designed to counter enemy sea mines. These are all systems in the “detect, classify, and identify” sea mines category or portfolio. Bubbles are sized according to resources expended over a 16 year period. Resources in this case include the acquisition costs over a six-year period plus ten years of operating and support costs. Risk is an amalgam of assessed values of the challenge in developing, transitioning, and operating a system. Finally, the numbers associated with each bubble are return on investments or, roughly, expected military value divided by cost, or bubble size. Further details on the portfolio analysis technique can be found at Chapter 9.

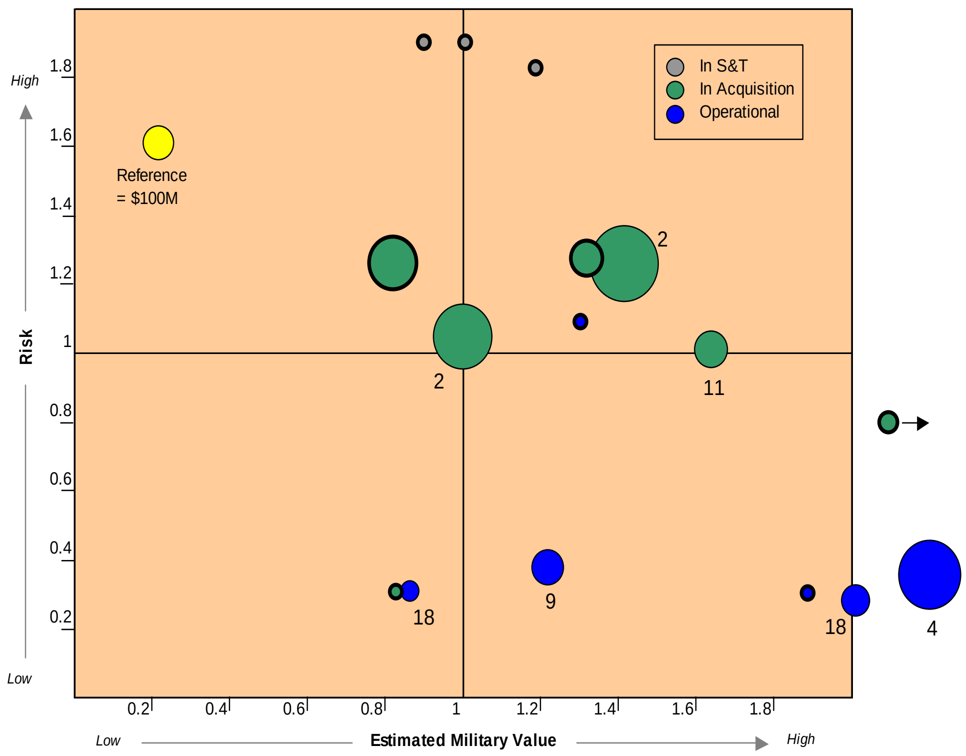


Figure 3-4: Military Balance of Investment Example.

3.3.9.2 Cost Benefit Analysis

Cost Benefit Analysis (CBA) is widely accepted as a vital support tool for economic analysis on defence programmes. It is primarily used:

- To assist decision makers.
- To provide transparency of issues.
- To quantify the effect of changes.
- To help in achieving national and multi-national consensus.
- To help to prioritise and compare projects.

A formal definition of an 'ideal' CBA might be:

> *"An objective study in which the costs and the benefits of a particular project's options are fully quantified in economic terms, taking full account of the times at which the costs are paid and at which the benefits accrue".*

Usually a CBA is conducted as a net present value analysis (see Sub-section 8.2.2.) by cumulating and discounting annual cash flows associated with a particular programme. On the basis of such an approach, summary statistics such as net present value, benefit/cost ratio, pay-off periods and internal rate of return can be determined.

In practice, things are not usually quite so straightforward. While costs and most types of benefits can generally be quantified after a little research, an economic breakdown of all the projected benefits can sometimes be more elusive.

The example shown at Figure 3-5 explores the benefits trade-off between live flying, synthetic training environments and aircraft in-service life in the provision of current and future heavy lift helicopter and light utility helicopter, rotary wing capabilities.

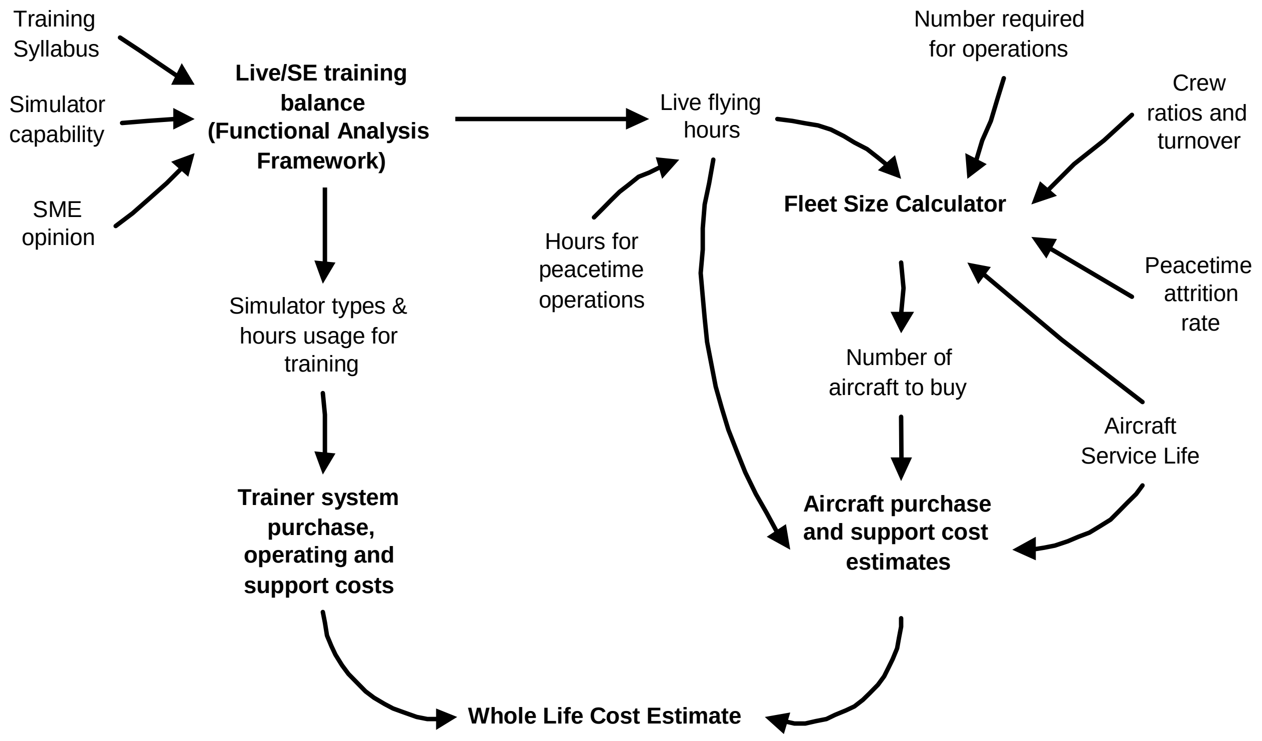


Figure 3-5: Benefits Analysis Example.

The figure presents a top level view of the influences affecting the whole life cost estimate. The items in bold text indicate calculation steps (and further influence diagrams) leading to the whole life cost output. Input data and intermediate data values are shown as regular text items.

In this instance the fleet size calculator, the functional analysis framework and the training system cost provide the study boundary and the mix of systems to be evaluated. The whole life cost estimates allowed the following analysis to be demonstrated:

- The most effective mix between the various aircraft and simulators.
- When to replace aircraft with simulators.
- The overall value of the return on investment.
- The timeframe of when the return can be expected.

3.3.9.3 Cost-Effectiveness Assessment

In the UK, this is typically referred to as a COEIA (Combined Operational Effectiveness and Investment Appraisal). Other nations may use different nomenclature, but in reality, it is the same type of analysis. The value of effectiveness is obtained by determining the principal attributes for MOPs (Measures of Performance) and MOEs (Measures of Effectiveness) and converting these to a single FOM (Figure of Merit). These provide the plots for the vertical axis. The life cycle costs (either constant or discounted) provide the measure for the horizontal axis.

Figure 3-6 illustrates a typical plot comparing performance and cost. The single value derived plots have been adjusted to allow for the uncertainty surrounding the weighting, scoring and cost. From these results the decision makers can choose which to take forward for further consideration.

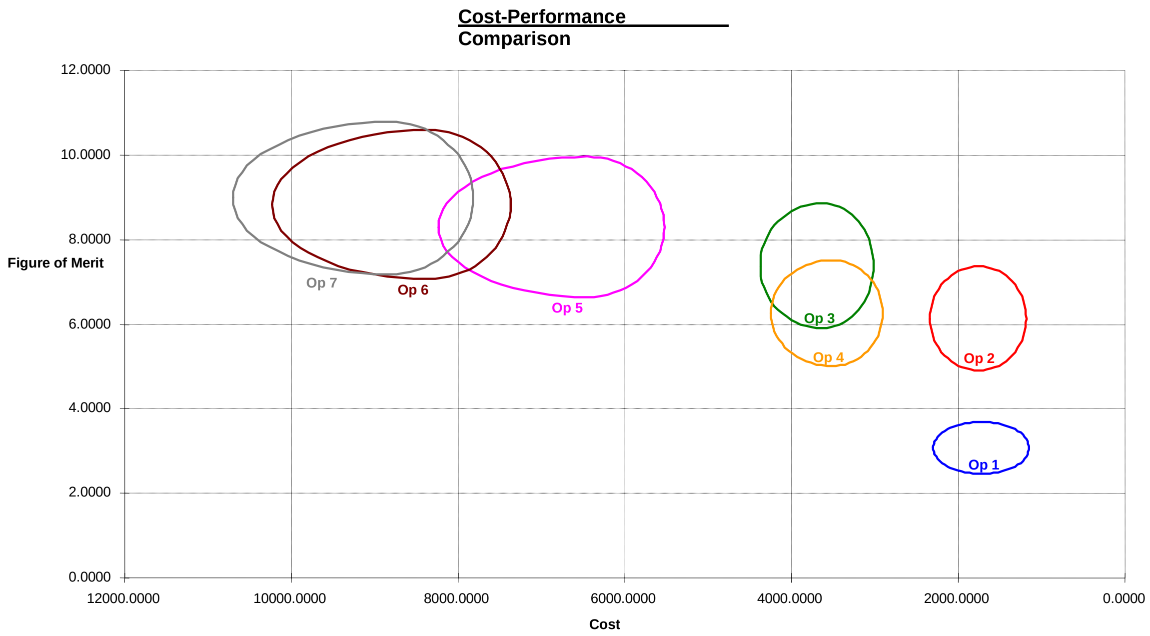


Figure 3-6: Cost-Performance Plot Example.

In this instance, Option 1 can be discounted as Option 2 provides better performance for the same cost. Option 4 can also be discounted as it provides the same level of performance as Option 2, but at larger cost. Options 5, 6 and 7 are significantly more expensive, but offer benefits in enhanced performance. Using this technique, the decision maker therefore has the means to be able to balance the level of acceptable performance with the cost available.

3.3.10 References

[1] UK MoD, General Instructions and Guidance on IAB and Delegated Approvals, Edition 8, March 2003, Annex F [unpublished MoD Documents].

[2] Decision Analysis for the Professional, Peter McNamee and John Celona (3rd Edition) – SmartOrg.

[3] Cost-Benefit Analysis: Concepts and Practice (2nd Edition) Anthony E. Boardman, David H. Greenberg, Aidan R. Vining, David L. Weimer, Prentice Hall (2000).

[4] Probability Theory: The Logic of Science, E.T. Jaynes, G. Larry Bretthorst, Cambridge University Press.

[5] Pidd, M. (2004), 'Systems Modelling – Theory and Practice', The Management School, Lancaster University, John Wiley & Sons Ltd.

[6] Warren, K. (2004), 'Competitive Strategy Dynamics', London Business School, John Wiley & Sons Ltd.

[7] Coyle, R.G. (2004), 'Practical Strategy – Structured Tools and Techniques', Bath University, Prentice Hall.

[8] Coyle, R.G. (1989), 'A Mission-orientated Approach to Defence Planning', Defence Planning, Vol. 5, No.4. pp. 353-367.

[9] British Standard EN 60300-3-3:2004, Dependability Management Application Guide – Life Cycle Costing.

[10] HM Treasury Supplementary Green Book Guidance (Joint Service Publication 507).

[11] UK MoD, Operational Analysis – Foundation for the Business Case, November 2003, Director General (Scrutiny and Analysis) [unpublished MoD Documents].

[12] www.ams.mod.uk

3.4 FEASIBILITY AND PROJECT DEFINITION PHASE

3.4.1 Summary Definition of Phase

This is where a broad outline of the function and desired performance of new equipment or weapon system is assessed. These phases will identify 'candidate' system options and solutions and identifies areas of technical risk. All the studies conducted during these phases will give an optimum balance between performance, cost and time. This will result in the provision of a preliminary estimate for the life cycle cost of the overall programme.

3.4.2 Inputs

These phases will commence with an agreed and fully documented NST (NATO Staff Target). During these two phases, the project changes from a theoretical state to a much more concrete one. The objective of the phases is to produce the full definition of the future product from its specifications (e.g. a precise description of what it will be from what it is meant to do).

These are the most important phases from a cost forecasting point of view since many of the decisions will have a profound and lasting effect on the project and on its future costs. In fact, so many aspects of the eventual system and programme requirements will be frozen during these phases that most of the cost reduction possibilities are forfeited during these phases. It is therefore extremely important that a high quality life cycle cost estimate is constructed and updated during the whole duration of these phases and that it must be used to support the various decision making processes. Typically, the following decisions are taken during these phases:

- The type of technology and material required to build the system.
- The type of contract and industrial structure (including future production rates, support modes and all smart acquisition related issues).
- The possible use of intermediate system introduction and incremental development.
- A strategy of how the system will be used and supported (e.g. ILS studies, etc.).

3.4.3 Outputs

The outputs from the feasibility phase will be a detailed NSR (NATO Staff Requirement) and, from the project definition phase, a NADDO (NATO Design and Development Objective). To complete these documents the life cycle cost estimates will be supported by industry data. Some design data will be

available. The life cycle cost estimates will be available at all the major line item level in the cost breakdown structure.

3.4.4 Life Cycle Cost Benefits

Life cycle costing is conducted at a much more detailed level than the previous phases. More information should be available on the system design and logistic support. This will make the life cycle cost and logistic support analysis much more substantive and meaningful.

3.4.5 Types of Life Cycle Cost Studies

The type of life cycle cost studies to be conducted during this phase varies according to the degree of precision required by the decision to be taken. In general, the costs become more precise and dedicated to some aspects of the programme as it progress in time. Typical examples of studies include:

- The evaluation of technological choices requiring an analytical description of the product, and the scope of the cost estimate may need to consider various sub-assemblies or even components within the whole system.
- Major procurement issues (depending on the proposed acquisition strategy) may require a much broader approach and necessitate expanding the costing boundary to include elements (e.g. facilities and personnel costs) often only considered at later phases in the programme.

When comparing different solutions, it is essential to verify that the costing boundaries (scope) considered in the life cycle cost estimates are consistent and that the capabilities provided are comparable. Particular note should be taken when no alternative solution is apparent. This would result in a decision to:

- Not to acquire the capability (which may have a political cost) or,
- To keep using existing systems (with, usually, increased in-service costs due to the need to overcome obsolescence or recover natural wear and tear).

In conducting life cycle cost estimates on multi-national programmes, great care must be applied to the assumptions of deployment. Although each nation may have slightly different deployment and supportability, for cost modelling purposes, a consensus should be agreed so that there is consistency in the life cycle cost outputs. In this way, optimised solutions can be evaluated to address both national and multi-national concerns.

3.4.6 Methods Employed

During the previous phases the life cycle costs would have been derived using a form of parametric approach with many assumptions. The risk assessment would have been conducted at a high level and, as expected, the overall level of uncertainty would have been significant.

During the feasibility and project definition phase the level of design detail available will be increased thus allowing for refinement of any parametric based estimate. This will be supplemented by information (e.g. system breakdown, component reliability, system maintainability, etc.) from industry and further information on the planned logistic support. This will allow a more detailed life cycle costing to take place and probably also using some optimization methods. Although in this phase more detailed information will become available, the method of analogy will still be used quite often employing in-house cost models. Also at this phase a detailed and fully quantified risk register should be available for conducting a cost risk analysis.

3.4.7 Life Cycle Costing Process

Figure 3-7 provides a simple illustration of the life cycle costing process. It shows that at this PAPS phase the source data to support the life cycle costing is likely to be more mature in terms of system engineering design therefore the total reliance on parametric approaches will be reduced, but the refined parameters should still be used as a sanity cross check. More data should now be available from industry and a more detailed population of the cost breakdown structure can commence. It should be possible to populate all the major line items in the cost breakdown structure.

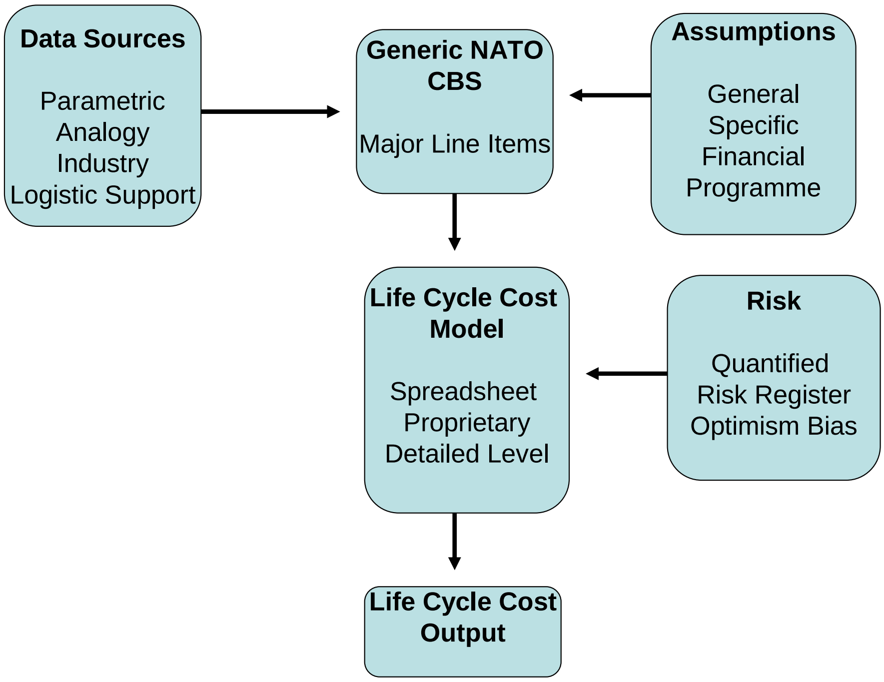


Figure 3-7: Simplified Feasibility and Project Definition Life Cycle Costing Process.

All the risks should now be captured and quantified within a risk register to provide the basis for conducting the cost risk analysis.

At the completion of this phase it should be expected that the life cycle cost output will be an understanding of the total programme costs (all major elements of the cost breakdown structure) and the level of uncertainty surrounding them. In summary, the key considerations to the life cycle costing process for this phase are:

- The principal data sources are likely to be parametric based and likely to be supplemented by information from industry.
- Some design data is likely to be available to refine the estimates and provide an initial baseline for the operating and support costs.
- The life cycle costing is likely to be conducted using in-house models and the results cross-checked and supplemented (if possible) using an alternative method. This provides two independently developed estimates to support the robustness of the life cycle cost estimate.
- There will be many ground rules and assumptions to be recorded and assessed.
- The risk will be measured at a reasonable level of detail probably utilising a quantified detailed risk register and cross-checked using an optimism bias technique.

- The life cycle costs are likely to be reported at the principal cost element level of the generic NATO CBS only as shown in Figure 10-1, but probably analysed at a slightly lower level of granularity.

3.4.8 Risk Assessment

In the feasibility and project definition phase a more detailed risk analysis will be conducted than in the earlier phase. The risk will be measured at as detailed a level as possible probably using a quantified risk register. If possible an optimism bias technique should be used. See for an overview of the optimism bias technique Appendix A to Chapter 7.

3.4.9 Example

As previously mentioned, this phase requires close, continuous collaboration between the research community, the user, and the developer as alternative technologies are assessed and as performance parameters are refined. As Figure 3-8 shows, life cycle cost estimates of alternative options are critical inputs in choosing the best future system or technology (Path 1 or Path 2, in this simple example) for meeting emerging war-fighter requirements.

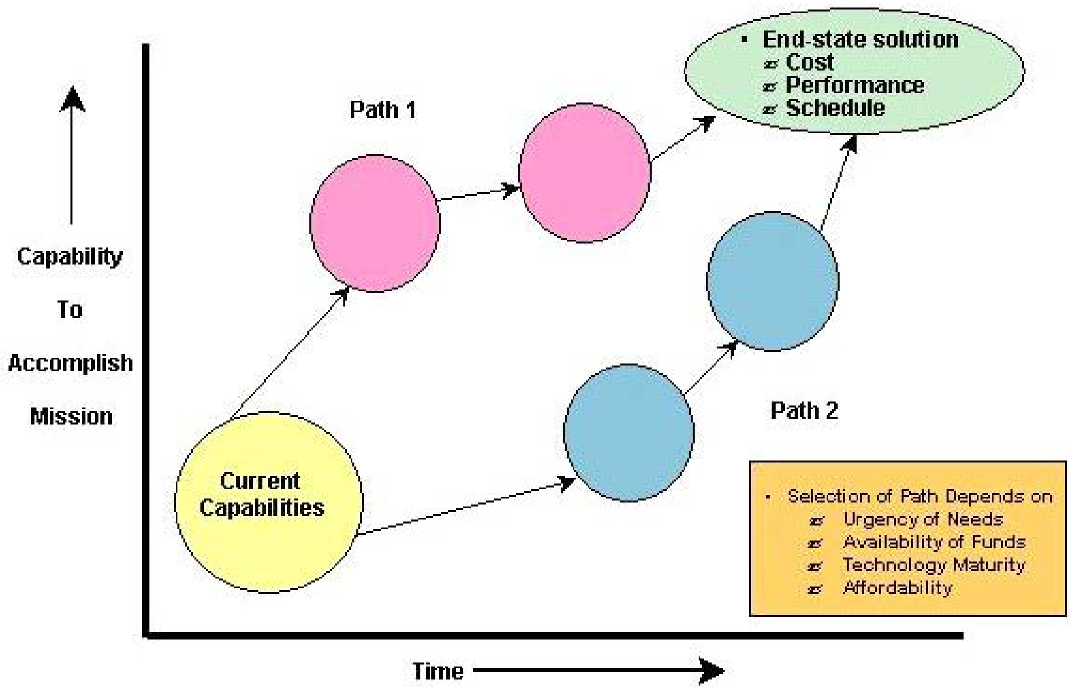


Figure 3-8: End-State Solution.

Given that several, different, potential technological solutions are typically examined, and given that user requirements are still very fluid, the method of choice for performing life cycle cost estimates in this phase is usually parametric. This allows for rapid analytical response to changes in technologies and user needs.

To take a concrete yet simple example (see Figure 3-9), assume a new satellite needs to be developed to detect stealthy enemy sea mines in very shallow water (VSW), in the littoral. The user community is unsure of their specific requirement concerning the size of enemy sea mines that it needs to detect. The range of user values is from one to three cubic metres. This requirement, in turn, drives the size and power of the sensor and, consequently, the size of the satellite bus and the number of thousands of sources

lines of code (KSLOC) to develop. Note that detecting a relatively small enemy sea mine requires a relatively powerful sensor and hence more lines of code and a bigger bus (to carry a bigger sensor).

CER Input Variables	User Requirements		
	A	B	C
Sensor Fidelity (size of sea mine)	1 cubic metre	2 cubic metres	3 cubic metres
Software (KSLOC)	250	150	100
Bus Weight (pounds)	1500	1100	1000

Figure 3-9: Example Sensor Fidelity to Software Size.

Three CERs are use to generate a cost estimate for development for each of the three cost elements:

- Payload (sensor)
  - Expected Cost = 3,568,510*(size of sea mine in cubic meters)$^{-0.87}$
- Software
  - Expected Cost = 435,216*(KSLOC)$^{0.91}$
- Bus
  - Expected Cost = 87,450*(Bus Weight)$^{0.79}$

Similarly, cost estimates for production and for operating and support are generated using parametric techniques. Finally, costs for each phase are rolled-up to produce life-cycle cost estimates for the three alternatives.

3.4.10 References

[13] Handbook on the Phased Armaments Planning System (PAPS), Allied Administrative Publication (AAP-20) PAPS, NATO Defence Support Division, 1989.

[14] UK MoD, Operational Analysis – Foundation for the Business Case, November 2003, Director General (Scrutiny and Analysis) [unpublished MoD Documents/Reports].

[15] www.ams.mod.uk

3.5 DESIGN AND DEVELOPMENT PHASE

3.5.1 Summary Definition of Phase

This phase of the programme calls for sufficient design engineering work to be conducted to ensure that full validation of the technical approach can be achieved. Also, the complete system integration is assessed to the point where production contract action can be taken.

3.5.2 Inputs

This phase commences with the NADDO (NATO Design and Development Objective) and is the phase where the earnest work on life cycle costing is performed. In this phase the design and development of the system being considered is well under way. An equipment, a system or a platform has been chosen and the

next step is to develop a final design and to choose a supplier. A lot of information from earlier phases may exist; in-house historical data, results from early tests and technical demonstration.

Ideally in this phase, a RFI (Request for Information) can be initiated and discussions can be held with several potential suppliers without commitment. This can provide several advantages. Information received from these contacts can provide a better understanding of the programme and introduce the opportunity to influence the life cycle costs by using market competition. The process also provides an opportunity to further develop the cost breakdown structure (greater transparency and higher precision). This approach to gaining data and information is also applicable in situations where only a single supplier is available.

In addition, the CONOPS (Concept of Operations) document should be used in conjunction with the ARM (Availability, Reliability and Maintainability) information provided by the supplier to refine the operating and support costs.

3.5.3 Outputs

On completion of this phase the life cycle costing will be sufficiently comprehensive and complete to support the NAPO (NATO Production Objective) and provide a realistic forecast of the likely total whole life cost.

3.5.4 Life Cycle Cost Benefits

The main purposes of life cycle costing in this phase are to:

- Influence the alternative solutions by evaluating the balance between life cycle costs and military capability.
- Support the system choice through using the results of the life cycle costing.
- Establish the logistic support requirements for the chosen solution to minimise the life cycle costs.

It is an established fact that many of the cost drivers are influenced by design decisions. The challenge for the system engineers is to balance the acquisition and support cost to provide the minimum life cycle cost. The life cycle costing activity plays a very significant role by providing data for systems engineering trade studies aimed at minimising the life cycle cost.

3.5.5 Types of Life Cycle Cost Studies

Entering the design and development phase concludes a decision to whether to make or buy a system off-the-shelf to meet the requirement capability. Since the design and development phase is a part of the "make track", there is a relative large extent of freedom in designing the end product.

The types of life cycle cost studies to be employed can be described in many dimensions. A split can be made between:

- A life cycle cost analysis that aims toward costing the production and operation of the system(s), and
- Costing the alternative effects of introducing the system into the organisation in addition to or incrementally replacing the first.

Experience shows that up to 80 % of the life cycle costs relating to the system can be influenced in the design phase. This demonstrates that significant resources should be allocated to the life cycle costing work to be conducted during this phase.

The life cycle costing studies should be performed as an iterative process with each cycle providing greater levels of completeness, granularity and clarification. Any changes to the design should be aimed at minimising the life cycle costs whilst meeting all the desired requirements. The life cycle costing work should focus on both the principal system and all supporting infrastructure.

Cost savings are often found during this iterative cost estimating process. It is therefore essential that a thorough analysis of all the cost elements is conducted at this phase.

3.5.6 Methods Employed

There are no limitations to what type of methods can be employed in this phase. For example, engineering, parametric, and analogy are all still applicable and can be used to produce a life cycle cost analysis of high quality. It is often found that a combination of these methods is useful particularly when used together with expert opinion.

However, in order to provide a high quality input to these methods, a close working relationship will need to be maintained with the system design team.

3.5.7 Life Cycle Costing Process

Previous life cycle costing studies will have been conducted by government departments or their agents using a variety of methods, various assumptions and predictive system design data. At this phase it is appropriate to firm up as much as possible on the assumptions and predictions by gaining further information from industry. The major steps to developing the life cycle costing further during this phase are:

- Issue a RFI (Request for Information), based on the cost breakdown structure, to several prospective suppliers requesting all the data to support a life cycle cost study of their proposed system.
- Conduct a life cycle cost study to identify the key cost drivers, the costs that can be influenced and the costs that differ between the alternative solutions.
- Validate the system specification based on a cost/benefit analysis and the associated risk and uncertainty.
- Evaluate the life cycle cost analysis to support the procurement decision.
- Iterate the process to resolve any conflicts between system performance and cost.

Each of these 5 steps is described in more detail below.

3.5.7.1 RFI and CBS from Vendors – LCC Comparison

During this phase, it may be possible to have a dialogue with several prospective suppliers in order to gain information to support the life cycle costing process. This can provide a better understanding of their systems and increase the possibility to influence the life cycle costs by making the cost breakdown data more transparent and with greater precision. This approach is also applicable in situations where there is only a single supplier. By using this approach, different product designs can be assessed in terms of a minimum life cycle cost solution.

To enable comparisons between different product designs, it is crucial to ensure that the costing boundary is consistent. For example, using the same definition for personnel cost in the cost estimates given by the suppliers or ensuring whether the personnel cost has been included or not. The Operating and Support cost

elements should be determined using an agreed CONOPS (Concept of Operations) to highlight all the deployment requirements.

It is also essential to understand how the life cycle costing has been conducted by the suppliers and the models they have used to conduct the analysis.

A risk register together with a quantitative risk assessment should be provided by each of the prospective suppliers. This should be based the suppliers ability to meet the requirements detailed in the NADDO (NATO Design and Development Objective).

All the data and information gathered from the prospective suppliers should be benchmarked against empirical data either from internal or external sources. This should diminish the risk of a biased life cycle cost analysis.

3.5.7.2 Cost Drivers – Influencing the LCC

When receiving the completed cost breakdown structure from the prospective suppliers the focus of the life cycle cost analysis should be on identifying the major cost drivers and avoiding becoming embroiled with too much detailed data. The focus on major cost drivers is needed in order to reveal potential areas of product design changes that could have a significant influence in minimising the life cycle cost at the earliest opportunity.

The focus of the analysis should also be on the cost drivers that enable comparability between the different product designs. It is more crucial to reveal the cost differentiation between differing product designs than estimating the likely total cost.

3.5.7.3 Validate the System Specification

The cost drivers are further analysed to understand the effects on both benefits (capabilities) and the cost of any possible changes. This would include requesting the suppliers to clarify data on the identified cost drivers. In the original data analysis, risk premiums with regards to new technology should be included and the suppliers risk analysis should also be reviewed together. The resulting analysis will support the decision making process and could result in adjustments being made to the final specifications in order to achieve a lower life cycle cost.

3.5.7.4 Evaluation and Iteration

In practice, life cycle costing should be part of the iterative process of the system design. The costing boundary defines exactly what elements should be included and the level of detail in which they will be considered. The life cycle costing activity during this phase should be sufficiently robust to support a ‘value for money’ decision. To achieve this level of confidence it may be necessary to iterate the life cycle costing process several times during the phase. It is essential to ensure that life cycle costing is not just a one-off activity. To be at its most efficient it needs to be integrated into the design process, be able to identify opportunities for cost savings and be accurate in terms of providing a robust and defendable life cycle cost.

Figure 3-10 provides a simple illustration of the life cycle costing process. It shows that at this PAPS phase the source data to support the life cycle costing is likely to be very mature in terms of system engineering design therefore there should be detailed design data (structure and ARM) available from industry. Logistic information providing support analysis and stockholdings should also be available. All this information will allow a detailed population of the cost breakdown structure. It should now be possible to populate all the line items in the cost breakdown structure.

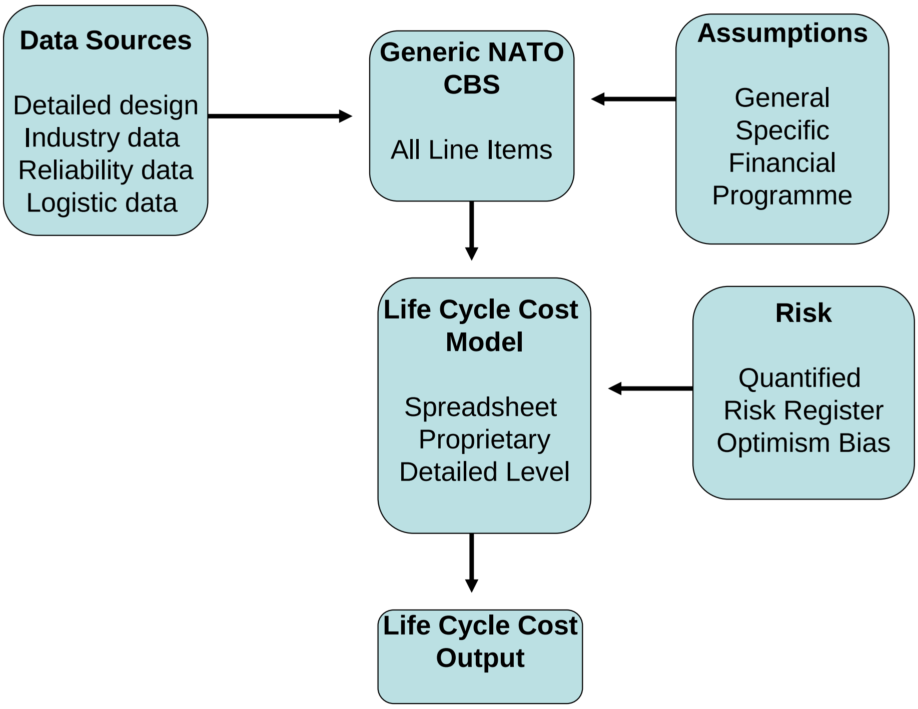


Figure 3-10: Simplified Design and Development Phase Life Cycle Costing Process.

All the risks should now be captured and quantified within a risk register to provide the basis for conducting the cost risk analysis. There should also be mitigation plans for all the major risk areas and the costs of undertaking these should also be included in the cost estimates.

At the completion of this phase the life cycle cost output should be a detailed account of all the line items contained in the cost breakdown structure. A comprehensive risk analysis in terms of Cost and Schedule impact should also be available.

In summary, the key considerations to the life cycle costing process for this phase are:

- The principal data sources are likely to be design and logistic information from industry supplemented by military data on likely deployment and staffing numbers.
- All design data and a comprehensive CONOPS report is likely to be available to refine the estimates and provide an established baseline for the acquisition, operating and support costs.
- The life cycle costing is likely to be conducted using in-house models and the results cross-checked and supplemented using an alternative method. A further independently generated estimate would provide a third view and provide the assurance and robustness of the life cycle cost estimate.
- All the ground rules will have been agreed. There will be few assumptions to be recorded and assessed. Although, it can be expected that the reliability and maintainability modelling will have been conducted using predictive data. The criticality of this data should be measured using sensitivity analysis.
- The risk will be measured at a detailed level utilising a quantified detailed risk register and recognised risk simulation models.
- The life cycle costs are likely to be determined at all the line items in the cost breakdown structure.

3.5.8 Risk Assessment

During these phases the identification of risk should be conducted at a very comprehensive level to fully understand the level of risk exposure to cost and time. All the mitigation plans should have been developed and programmed. The cost of conducting the risk mitigation actions should be included in the life cycle cost estimate.

The risk analysis should comprise pre and post risk mitigation scenarios as well as developing the time line for undertaking and completing the mitigation actions.

At completion of the phase the results of the risk analysis should provide a clear indication on the level of financial and timescale risk exposure to the programme.

3.5.9 Examples

A number of examples are shown that relate to the types of studies to be undertaken before and after contract award. It is important to distinguish these as the added value provided to this and the next phase is invaluable.

3.5.9.1 Analogy Cost Estimating

This cost estimating method is accomplished by forecasting the cost of the future based on the historical cost of a similar or analogous item. The costs of the historical item must first be normalised for both content and historical price differences. Normalising for content entails deducting the cost of components that are not comparable to the new design and adding estimated costs of the new components. Normalising for inflation entails converting historical cost to an appropriate base year value and applying the proper escalation indices to achieve then-year costs. Estimating by analogy involves comparing your system and/or cost breakdown structure elements to comparable current and or historical systems or cost breakdown elements. This involves understanding the programme and how it derives its history, for example, what programme it is based upon. It is important to interact with programme engineers to ensure the validity and credibility of candidate analogous programme to the future system; once comparable programmes are considered, it is necessary to seek out those specific systems if possible to obtain necessary data and cost information. The estimator will also need to talk to the programme engineers to understand differences between the future system and the comparable analogous system(s).[2]

Figure 3-11 is a simple example of estimation by analogy for military personnel pay systems. System A is old and system B is new. The objective is to estimate the software development effort for the new system. This is done using system A as an analogy, or more specifically, using man-months of effort per function point on A as the analogous ratio or multiplier, to be applied to the new system, B.

[2] NAVSEA 2005 Cost Estimating Handbook, p. 4-11.

System	Software Development Effort (Number of Manmonths)	Size of Software (Number of Function Points)
A	986	15,800
B	?	12,800

System	Manmonths Per Function Point
A	0.06

System	Software Development Effort (Number of Manmonths)
B	.06 x 12,800 = 799

Figure 3-11: Example of Analogy Cost Estimating.

Finally, complexity factors have often been used to adjust analogous estimates. However, they can often undermine the credibility of the future estimate if they have not been substantiated. For example, engineers might suggest that a new programme is twice as complex as an analogous programme, and that, therefore, the new programme's cost should be twice the cost of the old programme. In reality, the relationship between complexity and cost might be unknown. It could be proportional, linear, or exponential. Without hard data, a subjective adjustment will negate the credibility of the estimate.

3.5.9.2 Parametric Cost Estimating

Parametric estimating requires that a statistically valid relationship be established among the dependent variable, such as cost, and independent variables, such as costs of other elements, and or various physical and performance characteristics of that system. This parametric CER (cost estimating relationship) is then used to estimate the cost of a new system with different values for the same physical and performance characteristics.[3]

Provided below is an example, based on a dozen historical observations on number of man-months required for lead ship construction and the displacement tonnage of that ship. Note, that construction for the first ship in a class is typically a development contract, and includes non-recurring design effort.

First, a CER is estimated using least-squares regression analysis.

$$Y_i = 10.3 + 100.7X_i + e_i$$

(4.3) (3.2)

$n = 12$

$R^2 = 0.87$

$F = 17.1$,

where n = the number of historical observations used to estimate the equation.

Y_i = number of man-months required to construct the i^{th} ship (in millions).

X_i = displacement tonnage of the i^{th} ship (in thousands).

e_i = the i^{th} regression residual.

[3] NAVSEA 2005 Cost Estimating Handbook, p. 4-11.

R^2 = The coefficient of determination, or the proportion of variation of Y (dependent variable) that can be attributed to the variation of the explanatory or independent variables (X's). It is a measure commonly used to describe how well the sample regression line fits the observed data. Note that $0 <= R^2 <= 1$.

F = measures the overall power of the regression equation in explaining changes in the dependent variable. More specifically, it is used in testing the null hypothesis of no relationship between the set of X's (explanatory variables) and Y (the dependent variable).

and where t-statistics are shown in parentheses.

Then, a value for displacement tonnage for the new system is input into the estimated regression equation to give an estimate of man-months of effort required to design and construct the new ship.

3.5.9.3 Historical Trend Analysis

In addition to the estimating techniques discussed above conducting a historical trend analysis provides the estimator with the ability to set estimated costs and time schedules either separately or together in the context of historical costs for similar or related programmes. This is distinct from any cost estimating models themselves. Its uses are:

- To provide supplementary background information of a kind that can assist an estimator by giving a wider context to their work upon an individual programme.
- Similarly, by providing context and background to a study, it facilitates the work of those responsible for the scrutiny of estimates prepared by others e.g. as in auditing and due diligence work.

Figure 3-12 illustrates the estimated cost of a new programme in the context of historical trends as exemplified by the actual outturn costs of a substantial number of similar programmes completed in the past. All the costs having been normalised to common economic conditions and due allowance made for differences in scale. How well the estimated costs of the new programme fit into this context is both seen by the user in readily-understood graphical form and can also analysed statistically.

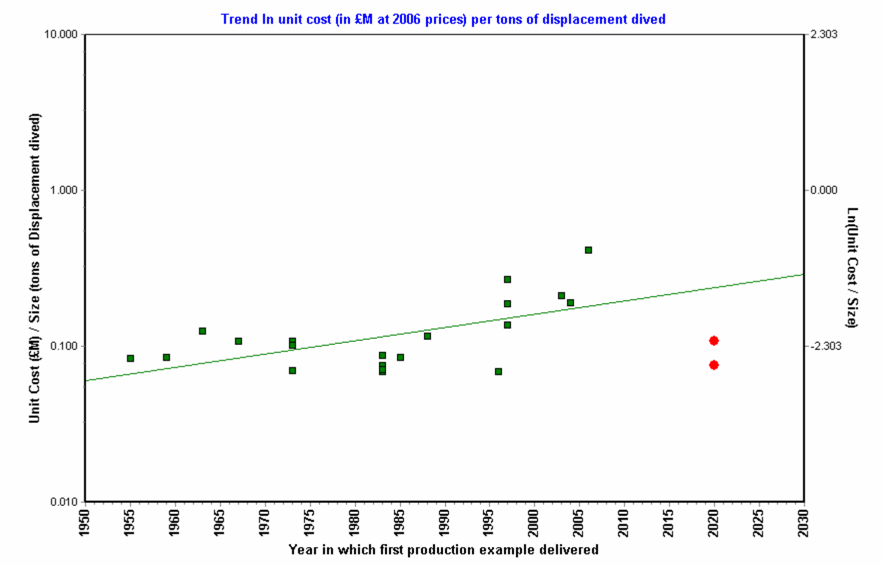


Figure 3-12: Example of Historical Trend Analysis.

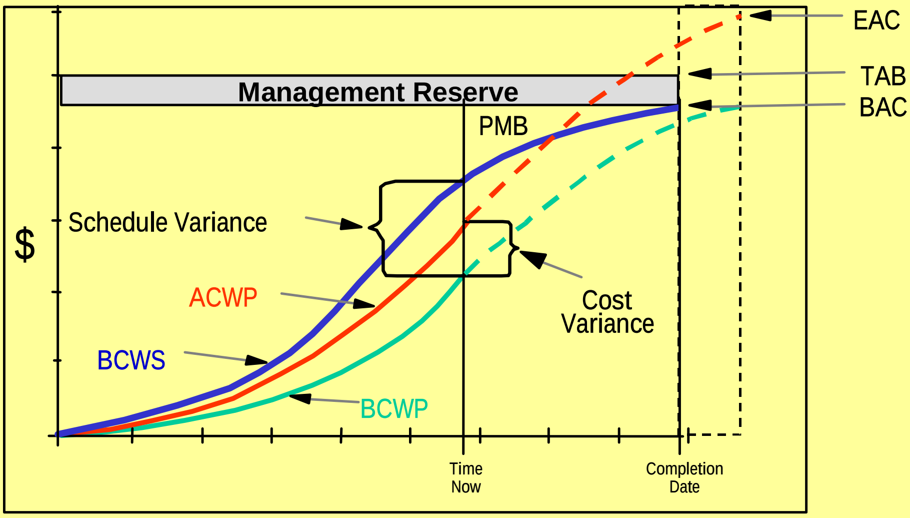
3.5.9.4 Example of Evaluation of Contract Performance

Once a contract has been awarded for design and development, or production, data from an EVM (earned value management) system can be employed as an aid to decision making. EVM is an integrated management control system for assessing, understanding, and quantifying what a contractor is achieving with programme funding. More specifically, EVM:

- Integrates technical, cost, and schedule information with risk management.
- Allows objective assessment and quantification of current project performance.
- Helps predict future performance based on trends.

Earned value provides an objective measurement of how much work has been accomplished on a programme. Using the earned value process, the management team can readily compare how much work has actually been completed against the amount of work planned to be accomplished. All work is planned, budgeted, and scheduled in time-phased ‘planned value’ increments constituting a PMB (Performance Measurement Baseline), or BCWS (Budgeted Cost of Work Scheduled) curve, as shown in Figures 3-13 and 3-14, which have been taken from the US Defense Acquisition University EVM Gold Card.

Defense Acquisition University
Earned Value Management Gold Card



VARIANCES *(Favorable is positive, Unfavorable is negative)*

- Cost Variance — CV = BCWP – ACWP — CV % = CV / BCWP
- Schedule Variance — SV = BCWP – BCWS — SV % = SV / BCWS
- Variance at Completion — VAC = BAC – EAC

PERFORMANCE INDICES *(Favorable is > 1.0, Unfavorable is < 1.0)*

- Cost Efficiency — CPI = BCWP / ACWP
- Schedule Efficiency — SPI = BCWP / BCWS

OVERALL STATUS

- Percent Complete $= \dfrac{\text{BCWP CUM}}{\text{BAC}}$
- Percent Spent $= \dfrac{\text{ACWP CUM}}{\textbf{BAC}}$

TO COMPLETE PERFORMANCE INDEX (TCPI)

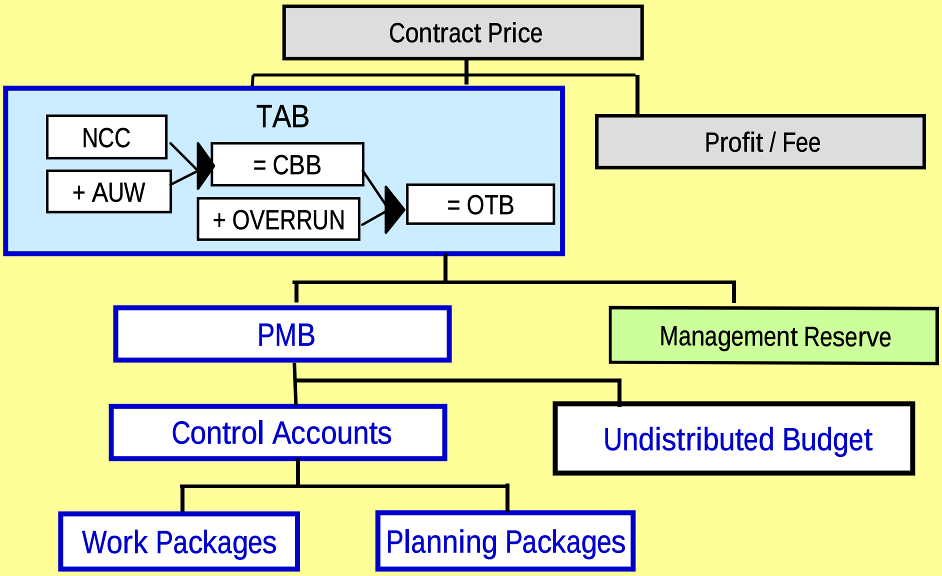
$$\text{TCPI}_{(\text{EAC})} = \frac{\text{WORK REMAINING}}{\text{COST REMAINING}} = \frac{\text{BAC} - \text{BCWP CUM}}{\text{EAC} - \text{ACWP CUM}}$$

ESTIMATE AT COMPLETION (EAC = ACWP + Estimate for Remaining Work)

$$\text{EAC}_{\text{CPI}} = \frac{\text{BAC}}{\text{CPI CUM}}$$

$$\bullet\ \text{EAC}_{\text{Composite}} = \text{ACWP CUM} + \frac{\text{BAC} - \text{BCWP CUM}}{(\text{CPI CUM}) \bullet (\text{SPI CUM})}$$

Figure 3-13: Example EVM Calculations.



TERMINOLOGY

NCC	– Negotiated Contract Cost	Contract price less profit / fee
AUW	– Authorized Unpriced Work	Work authorized to start, not yet negotiated
CBB	– Contract Budget Base	Sum of NCC and AUW
OTB	– Over Target Baseline	Sum of CBB and recognized overrun
TAB	– Total Allocated Budget	Sum of all contract budgets - NCC,CBB or 0TB (includes MR)
BAC	– Budget At Completion	Cumulative BCWS - total end point of PMB (excludes MR)
PMB	– Performance Measurement Baseline	Contract time-phased, budgeted work plan (excludes MR)
MR	– Management Reserve	Contractor PM's Contingency budget
UB	– Undistributed Budget	Broadly defined activities not yet distributed to CAs
CA	– Control Account	Contractor key management control point - CWBS element
WP	– Work Package	Near-term, detail-planned activities within a CA
PP	– Planning Package	Far-term CA activities not yet defined into detail Work Packages
BCWS	– Budgeted Cost for Work Scheduled	Value of work scheduled -- PLAN
BCWP	– Budgeted Cost for Work Performed	Value of work completed -- EARNED VALUE
ACWP	– Actual Cost of Work Performed	Cost of work completed -- ACTUAL COSTS INCURRED
EAC	– Estimate At Completion	Estimate of total contract costs

EVM POLICY (DOD 5000.2-R)

ALTERNATIVE EV MANAGEMENT APPLICATIONS

LEVEL 1. EVMS Industry Standards Management Application

Contractor management system certified as meeting Industry Standards

- Required for non-FFP contract exceeding $73M RDT&E or $315M in procurement (CY00$).
- PM may apply to contracts below-threshold —consider benefits, risk and criticality.
- Contractor must establish, maintain, and use a system that meets the the 32 Industry Standards.
- Cost Performance Report (CPR) delivered as a CDRL item.
  - 5 Formats (WBS, Organization, Baseline, Staffing, and Explanations)

LEVEL 2. C/SSR Management Application

Contractor Management system not certified

- Required for non-FFP contract exceeding $6.3M (CY00$) and 12 months in length.
- 'Reasonably objective' EV methods acceptable, traceability at higher level (CA vs WP)
- The CPR or the Cost/Schedule Status Report (C/SSR) delivered as a CDRL item.

EVM Home Page — http://www.acq.osd.mil/pm/
DSMC EV E-Mail Address — EVM@DSMC.DSM.MIL
DSMC EV Phone No. — (703) 805–2848/2968 (DSN 655)

June 2000

Figure 3-14: Example EVM Process.

As work is performed, it is 'earned' on the same basis as it was planned, in monetary or other quantifiable units such as labour hours. Comparing earned value with the planned value measures the monetary value of work accomplished versus the monetary value of work planned. Any difference is called a schedule variance.

Earned Value – Planned Costs = Schedule Variance (SV)

The value earned for the work performed compared with the actual cost incurred for the work performed (taken directly from the contractor's accounting systems), provides an objective measure of cost efficiency. Any difference is called a cost variance.

Earned Value – Actual Costs = Cost Variance (CV)

A negative variance means more money was spent for the work accomplished than was planned. Conversely, a positive variance means less money was spent for the work accomplished than was planned to be spent. Finally, as the figures indicate, cost and schedule variances can be used to generate estimates of contract cost at completion (EACs).

3.5.10 References

[16] NAVSEA 2005 Cost Estimating Handbook, http://www.navsea.navy.mil/sea017

[17] Earned Value Management Implementation Guide, Defense Contract Management Agency, October 2006; available from http://guidebook.dcma.mil/79/evmigoldversion.doc

[18] U.S. Defense Acquisition Guidebook available from http://akss.dau.mil/dag

[19] DoD Instruction 5000.2 "Operation of the Defense Acquisition System", May 2003 available from http://akss.dau.mil/dag

[20] UK MoD, General Instructions and Guidance on IAB and Delegated Approvals, Edition 8, March 2003 [unpublished MoD Documents/Reports].

3.6 ALTERNATIVE PROCUREMENT PHASE (MAKE OR BUY DECISION)

3.6.1 Summary Definition of Phase

As described in Section 3.2.9 this alternative procurement phase replaces a design and development phase and the production phase to represent a situation where an off-the-shelf buy (instead of a make) decision is made. In this situation, only a limited number of activities can be expected.

3.6.2 Inputs

The input for the alternative procurement phase is the agreed and fully documented NATO Staff Requirement. However, the level of detail required (in terms of performance and supportability) from industry would be far more substantial. This would be gained from formal approaches such as an RFI (Request for Information) or a more contractual RFQ (Request for Quotation). If there are more than one potential suppliers then a tender competition may be conducted and the ITT (Invitation to Tender) could comprise a life cycle cost questionnaire (see Annex C for an example) for completion by the contractors.

3.6.3 Outputs

The life cycle cost outputs should be sufficient to fully understand, on a year by year basis, all the acquisition, operating and support costs over the life of the programme.

The output of the alternative procurement phase will be a product or system that complies with the NATO Staff Requirement.

3.6.4 Life Cycle Cost Benefits

The main purposes for conducting life cycle costing on an off-the-shelf procurement programme is to provide the decision maker with a full understanding of the financial commitment over the life of the programme.

3.6.5 Types of Life Cycle Cost Studies

The type of life cycle cost studies to be conducted in this phase can be summarised as follows:

- Supporting the tender evaluation process.

  In the tender evaluation process the life cycle costing methodology can be used to ensure that the contract is award to the tender offering a system that meets all technical and availability requirements at minimum life cycle cost. The cost of investment in maintenance resources and the cost of lifetime support will be weighed against the cost of investment in the technical system. The resulting life cycle cost will be included in the overall tender evaluation period.

- Comparing alternative solutions or options on costs, in order to choose the best solution.

  As part of the alternative procurement phase various alternatives need to be compared. In some cases, the tender evaluation process may have to evaluate several options provided in the tender response all of which may meet the requirements (including direct procurement or a lease option). Or it may be that a nation would like to compare various types of support: e.g. own maintenance organisation versus outsourcing. In this case it is not necessary to estimate all cost elements. It may be sufficient only to estimate the cost elements that will show differences between the options. These relative comparisons however, will not provide a complete picture of the life cycle costs, but would be an aid to the decision making process.

- Determining the total life cycle costs

  In order to make a fair decision in the procurement phase, a nation would need to have an overview of the total life cycle costs, not only to determine the forecast of future spending, but also to assess the affordability of a procurement programme. In this case, all the cost elements have to be estimated and a detailed cost study is required.

3.6.6 Methods Employed

Dependent on the data available, many methods may be used in this phase:

- Engineering method.
- Parametric method.
- Analogy method.
- Expert opinion.
- Rules of thumb.
- Catalogue.

For more details on these methods see Chapter 4.

3.6.7 Life Cycle Costing Process

The major steps to follow are similar to the process described in Section 3.5.7. However, in an alternative procurement phase it is conducted in less detail.

- Based on the system requirements described in the NATO Staff Requirements an RFI/RFQ/RFP/ITT is compiled and sent to several companies and they are asked to answer cost related questions and fill in data in an agreed cost breakdown structure format. This will include a statement on the definitions and the basis of the cost estimate.
- Gathering data from internal sources in order to complete the cost model.
- Data analysis to find cost drivers, costs that can be influenced and costs that differ between the alternative solutions.
- Evaluate the result, either to support the procurement decision or to iterate the process until the basis for decision is clearly understood and agreed.

More details are provided at Sub-section 3.5.7. Figure 3-8 can also be used for the alternative procurement phase.

3.6.8 Risk Assessment

During the tender evaluation the identification of risk should be conducted at a very comprehensive level in order to fully understand the level of risk exposure. All the risk mitigation plans should have been developed and programmed and assigned to owners. The cost of conducting the risk mitigation actions should also be included in the life cycle cost estimate.

The risk analysis should comprise pre and post risk mitigation scenarios and should develop the time line for undertaking and completing the mitigation actions. At completion, the results of the risk analysis should provide a clear indication on the level of financial and timescale risk exposure to the programme prior to contract negotiation.

3.6.9 Example

The multi-national NSHP (Nordic Standard Helicopter Programme) is an example of how the life cycle costs can support the tender evaluation process.

All the participating nations' requirements were implemented in a common Nordic Requirements Document. This document defined those requirements that were considered common and those which were specific to a particular nation. The request for quotation required prospective contractors to provide detailed data to enable the evaluation of performance and reliability. In addition, this information would be used to estimate the life cycle cost. The evaluation of system availability and life cycle cost were performed for each participating nation's individual life cycle cost model.

Figure 3-15 represents a summary of user data and tender data that was included in each nation's life cycle cost model. The figure also shows how the calculated estimates for cost of spare parts were used as input to the model. All the nations' specific life cycle cost models were then combined in a total life cycle cost model, representing a combined life cycle cost for all the participating nations.

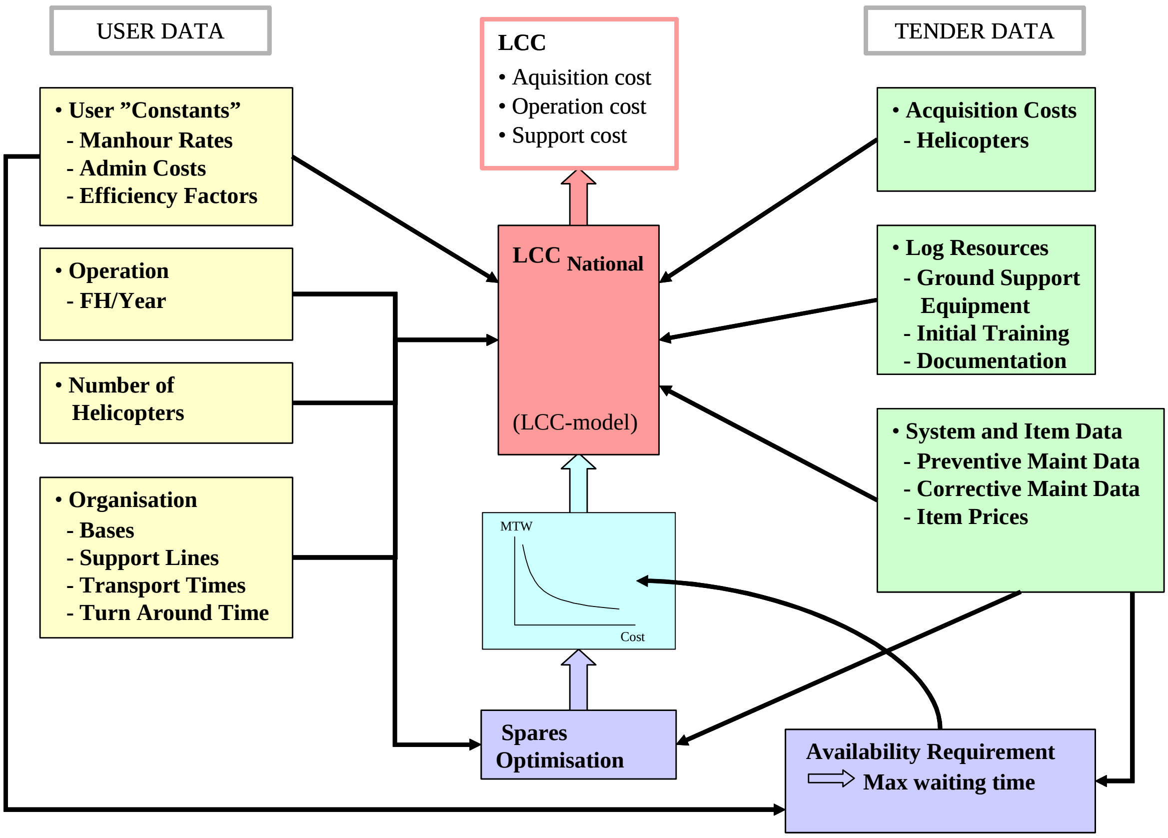


Figure 3-15: LCC Data Process.

The requirement for spares was calculated, by the procurement agency, using a logistics and spares optimisation model, based on the individual nation's operational profile. The criterion for the cost modelling was based on the MWT (Mean Waiting Time) for spare parts together with the unavailable time due to preventive and corrective maintenance. The system availability requirement was given as 80% (see Figure 3-16). By using this approach all the tenders were normalised and compared using the same performance level. The calculated costs for spare parts were used as an input to the life cycle cost evaluation.

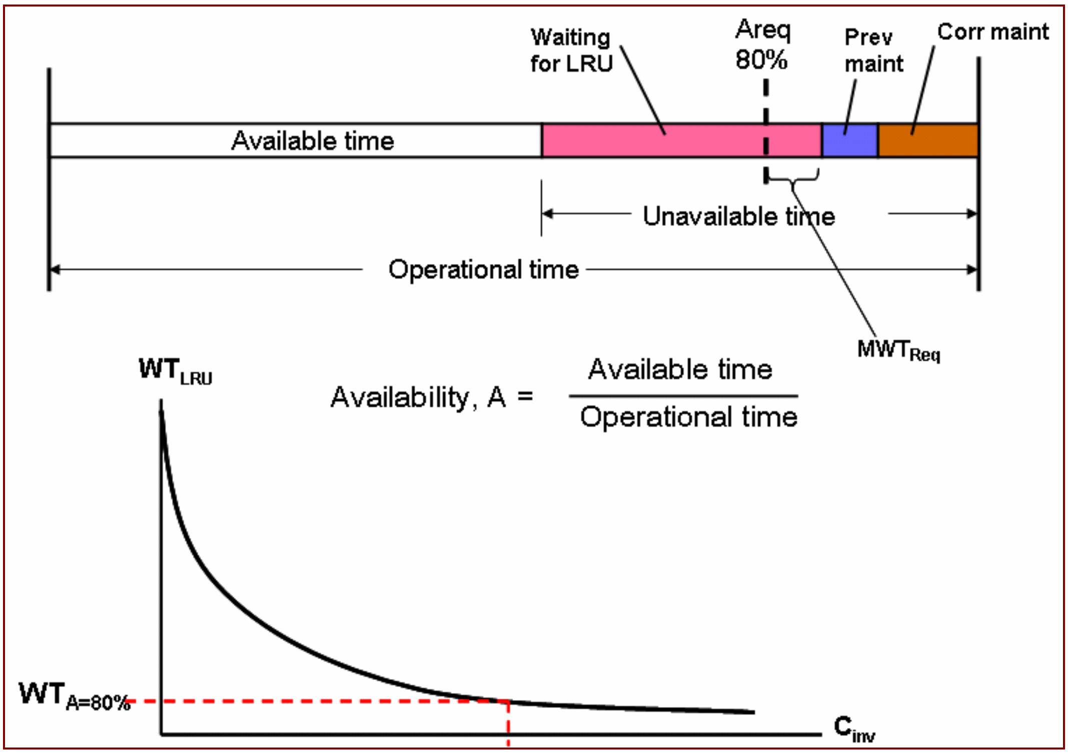
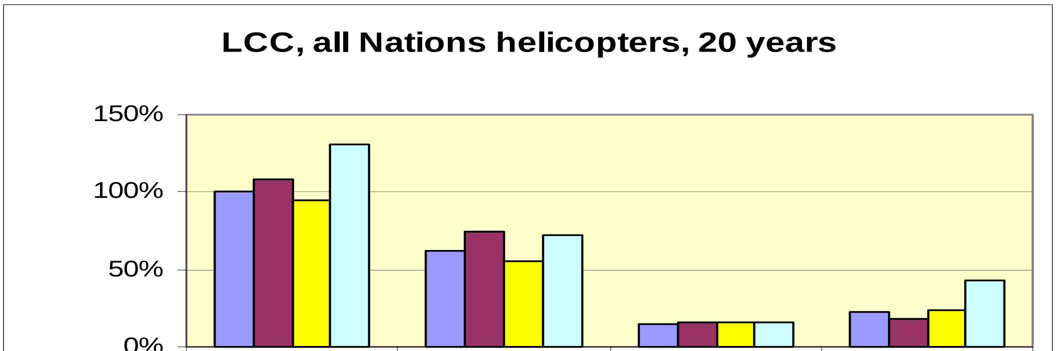


Figure 3-16: Availability Precedence.

Some of the results from the life cycle cost tender evaluation are presented below. Figure 3-17 shows the sum of all the participating nations' life cycle costs per tender. The cost for total life cycle cost, acquisition, operation and life support have been normalised to Tender F to provide a relative comparison. The life cycle cost tender evaluation process generated many different diagrams that presented different aspects and the cost drivers for each tender.



	LCC	Acquisition Cost	Operation Cost	Life Support Cost
Tender F	100%	62%	15%	23%
Tender G	108%	74%	16%	18%
Tender H	94%	55%	15%	24%
Tender J	131%	72%	16%	43%

Figure 3-17: LCC Evaluation Results.

When analysing the LSC (life support costs) (Figure 3-18) in more detail it became clear that the investment in spare parts differed significantly between the tenders. The difference was explained by the different maintenance concepts offered by each contractor.

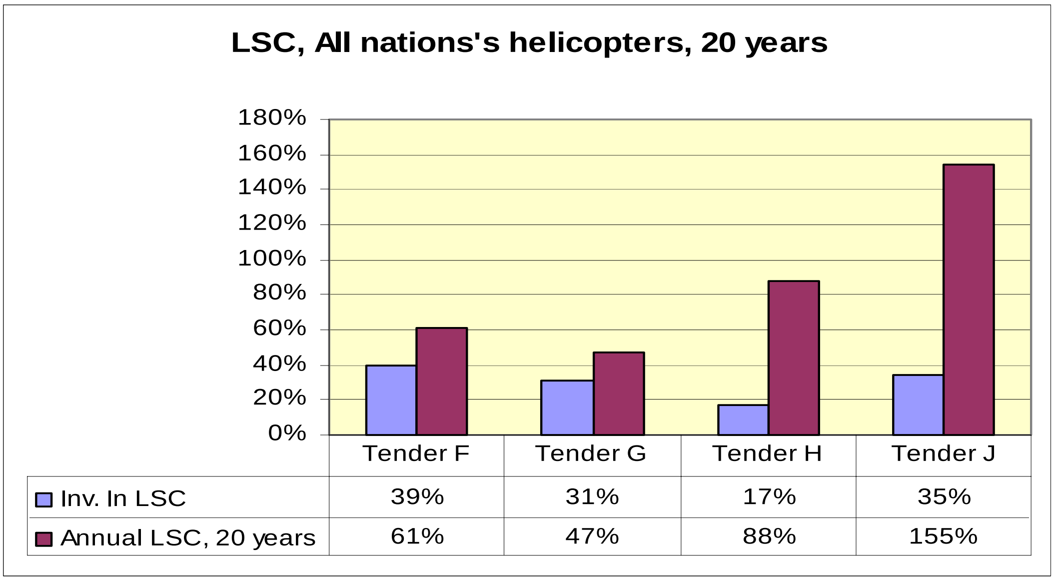


Figure 3-18: LSC Evaluation Results.

Figure 3-17 shows that Tender H has the lowest costs, however Tender F was selected as the winning tender due to other considerations. The life cycle cost analysis results were used as a baseline for negotiating the contract. In addition, the life cycle cost analysis is now being used to establish a support cost baseline prior to negotiating a contractor logistic support contract.

3.6.10 References

[21] Handbok för driftsäkerhet (H DriftSäk), 2006, (M 7740-714001 H Driftsäk), Swedish Armed Forces and Swedish Defence Materiel Administration. (in Swedish).

[22] Stappenplan voor het Analyseren van Levensduurkosten binnen de Defensie Organisatie (SALDO), FEL-93-A337, december 1993, B. Bhola and J.A.M. van Wees (in Dutch).

[23] Aanwijzing DGM inzake levensduurkosten bij materieelprojecten, aanwijzing 98-4 d.d. 11 december 1998 (in Dutch).

3.7 PRODUCTION PHASE

3.7.1 Summary Definition of Phase

This phase starts with the approval of the NAPO (NATO production objective). The NAPO is an outline statement of the manufacturing process, personnel and facilities required for production of the equipment, including an outline production programme based on cost plans, quality control requirements, and the stated production specifications. This phase includes the manufacture of a system, sub-system or equipment in a plant or factory using series manufacturing techniques.

3.7.2 Inputs

Assuming that the project does not include a combined design and development and production phase the inputs can be defined as:

- The project has achieved a level of maturity that will enable the final delivered product to satisfy the documented capability as defined in the NATO Staff Target and NATO Staff Requirement.

3.7.3 Outputs

Assuming that the project does not include a combined design and development and production phase the outputs can be defined as:

- At the end of production phase the product complies with NATO Staff Requirement Document or is supported with an incremental plan achieve the NATO Staff Requirement.

3.7.4 Life Cycle Costing Benefits

During the production phase the life cycle cost estimates made on the product components will change either because of component obsolescence, change in design or integration with other components/ systems. All of these factors will have a direct impact on the Systems Life Cycle Management Plan[4]. Therefore it is essential that any revised data is collected so that budgets and plans can be amended accordingly.

3.7.5 Types of Life Cycle Cost Studies

During the production phase the only related life cycle costing study is the review and update of the financial element of the systems life cycle management plan. Other life cycle costing studies may be initiated if there is radical change brought about by the failure to achieve the forecasted plan or a change in policy or procurement strategy by the participating nations in the joint project.

3.7.6 Methods Employed

3.7.6.1 Prior to Start of Production

To ensure that there is a sound basis for tendering/contracting the programme must have completed its design and development phase and a full production requirements specification is available. The arrangement for work share between participating nations must also be defined.

To enable suppliers to estimate costs and gain an understanding of the full requirements the acceptance standards must also be defined and documented.

To form a sound basis for both industry and government (including the commitment by the Armed Services during tests and trials) to plan their commitment to the project, the participating nations must supply a document that defines the equipment and specialist support they intend to supply free of charge (government funded equipment and the government funded support known collectively as GFX).

If there is no competition for the programme (single source supply) government investigating departments must be provided with adequate information from the suppliers to enable an assessment to be made of the reasonableness of the quotation. Therefore the invitation to tender document should be used to detail all the deliverables and acceptance criteria that will enable the authority to make an assessment of the contractors bid submission. A typical request for information is shown at Annex B.

[4] Policy for Systems Life Cycle Management C-M(2005) 0108-AS1, January 2006.

To provide assurance and programme control the bid submission must be soundly based, with key risks to performance, cost and timescale identified, and actions planned to monitor, mitigate and control those risks. Depending on the circumstances and the number of participating nations consideration should be given to the combining of the risk registers prior to tendering. ***If this cannot be done prior to tendering then it is recommended that a joint risk register should be developed as soon as the contract is agreed***.

The contract must meet the national and international requirements for contract law.

Experience has also shown that in a series production environment a correlation can be established between the reduction of production time and the quantities produced. Details on the theory and application are given in the example at Section 3.7.9.

The learning factor here equates to both the production quantity and the spares. Care must be taken to ensure that all cost benefits arising from increased quantities (learning) must be taken into account.

3.7.6.2 During Production

The primary focus here will be to assess how the forecasted costs compare to the actual cost, particularly those that relate to the in-service element.

The cost element of the systems life cycle management plan should be refined during the course of production to reflect refined product and sub component life cycle information (e.g. MTBF, MTTR, etc.).

Regular joint reviews of the systems life cycle management plan must take place to ensure that impacts can be assessed.

Review the integrated test, evaluation and acceptance plan. This will ensure you that there are adequate means to demonstrate that the equipment is fit for service.

The supplier shall provide progress reports either by EVM (Earned Value Management) or equivalent reports.

Regularly review the risk register and risk mitigation plans.

3.7.6.3 Post Production

To inform follow-on projects a post stage evaluation report should be prepared to ensure that best practice is captured and any weaknesses for future redress are exposed.

It is recommended that all actual costs incurred by the contractor are certified. This data can subsequently be used to refine and calibrate future cost forecasting models.

3.7.7 Life Cycle Costing Process

Figure 3-19 provides a simple illustration of the life cycle costing process. It shows that at this PAPS phase the source data to support the life cycle costing is likely to be very mature in terms of system engineering design. Quotations for production should be available together with all the logistic information required to model the supportability of the system over the expected lifetime. The cost breakdown structure should now be fully populated to provide a comprehensive view of the life cycle costs.

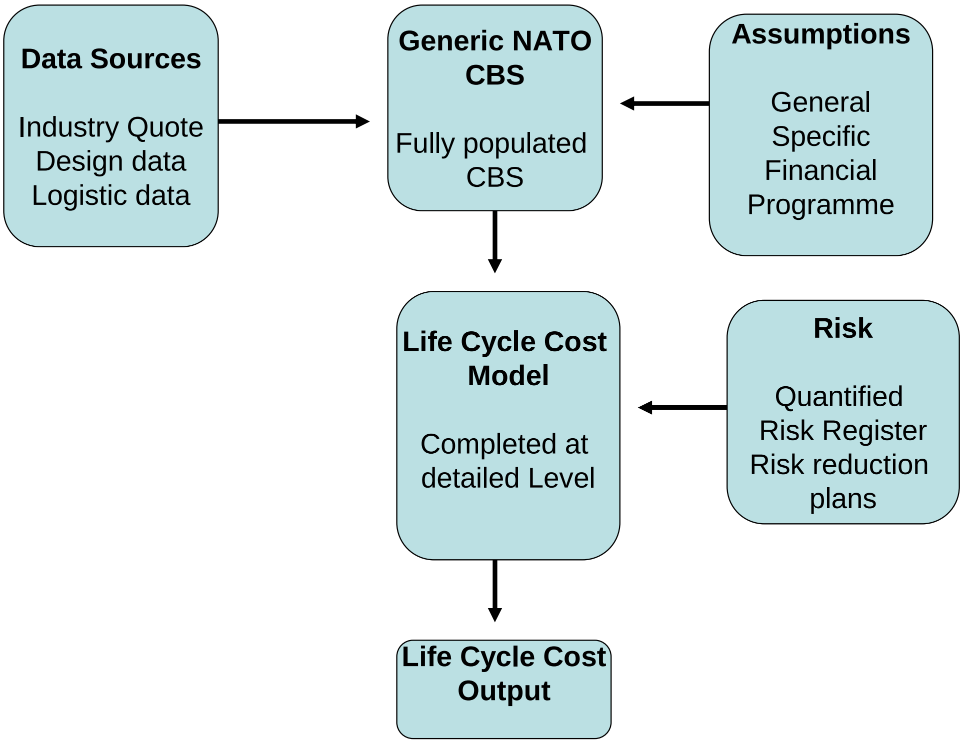


Figure 3-19: Simplified Production Phase Life Cycle Costing Process.

All the risks (both government and industry) should now be captured and quantified within a joint risk register to provide the basis for conducting the cost and schedule risk analysis. There should also be mitigation plans for all the risk areas and the costs of undertaking these should also be included in the life cycle cost estimates.

During this phase the life cycle cost output should be a detailed account of all the line items contained in the cost breakdown structure. It can be used to support the population of the production activity plan and subsequent cost control processes such as earned value management. A comprehensive risk analysis in terms of cost and schedule impact should also be available. In summary, the key considerations to the life cycle costing process for this phase are:

- The principal data sources will be firm/fixed price quotations from prospective suppliers supplemented by military data on likely deployment and staffing numbers.
- All design data and a comprehensive CONOPS report is likely to be available to refine the operating and support cost estimates and provide a robust baseline for supportability assessment and long term financial budgeting.
- The life cycle costing will be done at a detailed level.
- There will be very few assumptions to be recorded and assessed. Although, it can be expected that the reliability and maintainability modelling will have been conducted using predictive data. The criticality of this data should be measured using sensitivity analysis.
- The risk will be measured at a detailed level utilising a quantified detailed joint risk register.
- The life cycle costs are likely to be determined at all the line items in the cost breakdown structure.

3.7.8 Risk Assessment

During the production phase all the risks will be reviewed and managed on a regular basis. Mitigation plans will be put into action and their progress monitored. This will be a comprehensive management and analysis activity and will regularly report the possible outcomes in cost and schedule to the project manager.

3.7.9 Example

An example of cost analysis activities conducted at this phase include the use of cost improvement curves also referred to as the learning curve theory.

According to this theory, as the cumulative production quantity increases, unit production costs decrease. This can be due to an increase in workers skill levels, improved production methods, and/or better production planning. This effect can be quantified in production cost estimates using a product improvement curve, or a learning curve. A 90 % learning curve means that, each time the cumulative production quantity doubles, the production time (or, comparatively, the production cost) will be 90 % of its value before the doubling occurred. The standard measure of organisational experience in the learning curve formulation is the cumulative number of units produced, which is a proxy variable for knowledge acquired over production. If unit costs decrease as a function of such knowledge, organisational learning in some form is said to occur.

In actuality, unit (or Crawford's) learning curves may vary considerably depending on the expected magnitude of the cost savings estimated for the 2nd unit and so on. Because of the product complexity, an 80 % unit cost reduction may not be realised until the production of the following units. Cost analysts should evaluate the complexity of tasks in the production process and attempt to determine the type of unit learning curve that is most appropriate for the specific situation.

The equation used in Crawford's model[5] is:

$$\mathbf{Y = aK^{b}}$$

where:

a	=	time (or cost) required to produce the first unit.
Y	=	the incremental unit time (or cost) of the lot midpoint unit.
K	=	the algebraic midpoint of a specific production batch or lot.
b	=	percent change in cost divided by the percent change in quantity.

The unit cost of the mid-point unit is the average unit cost for the production lot.

Sometimes, in the application of learning curves, it may be more appropriate to use a cumulative average learning curve. If it turns out that the projected average cost of producing the first 20 units is 80 % of the average cost of producing the first 10 units, then the process follows an 80 % cumulative average learning curve.

[5] The theory of the learning curve or experience curve is based on the simple idea that the time required to perform a task decreases as a worker gains experience. The basic concept is that the time, or cost, of performing a task decreases at a constant rate as cumulative output doubles. Learning curves are useful for preparing cost estimates.

There are two different learning curve models. The original model was developed by T. P. Wright in 1936 and is referred to as the Cumulative Average Model or Wright's Model. A second model was developed later by a team of researchers at Stanford. Their approach is referred to as the Incremental Unit Time (or Cost) Model or Crawford's Model.

In Wright's model, the learning curve is defined as

$$\mathbf{Y = aX^{b}}$$

where:

a = time (or cost) required to produce the first unit.

Y = the cumulative average time (or cost) per unit.

X = the cumulative number of units produced.

b = percent change in cost divided by the percent change in quantity.

Figure 3-20 gives an example of a learning curve.

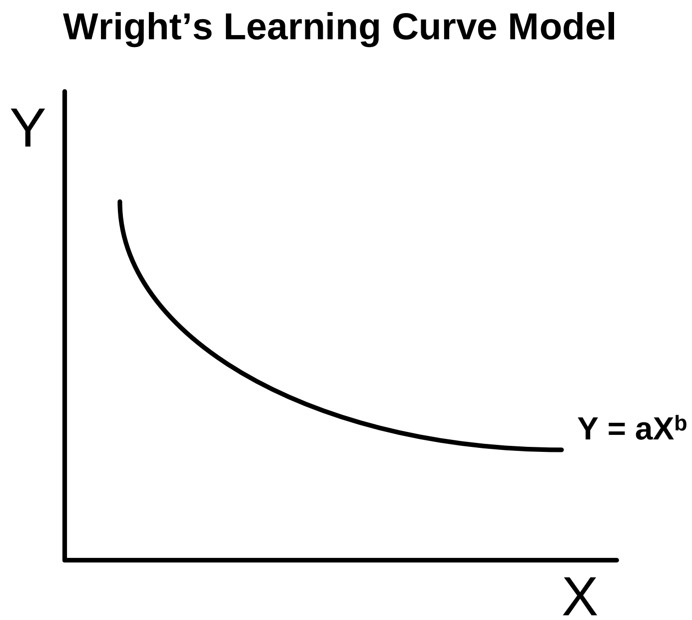


Figure 3-20: Learning Curve Example.

3.7.10 References

[24] www.ams.mod.uk

[25] Life Cycle Cost Policies Based on Learning Curve Concepts, Lt Col Massimo Pica, Ministry of Defence, Directorate General of Land Armaments, Rome, Italy.

[26] US Air Force Analyst's Handbook, Christopher A. Feuchter, January 2000.

[27] The "Mother of all Guesses", A User-Friendly Guide to Statistical Estimation, Francois Melese and David Rose, Armed Forces Comptroller, 1998.

[28] Unit Cost – a Financial Management Tool for Today and Tomorrow, Comptroller of the Department of Defense, 1990.

[29] U.S. Air Force Life Cycle Management Plan (LCMP) Guide, March 2005 https://acc.dau.mil/GetAttachment.aspx?id=32631&pname=file&aid=6197

[30] Statistical Methods for Learning Curves and Cost Analysis, Matthew S. Goldberg and Anduin E. Touw, 2003.

3.8 IN-SERVICE PHASE

3.8.1 Summary Definition of Phase

This phase starts with the NISEG (NATO in-service goals). The NISEG is a statement of the general utilisation intentions for equipment including reference to national or co-operative logistic and training arrangements.

The NATO PAPS defines the in-service phase as "the operational utilisation of equipment by nations". This utilisation phase is executed to operate the product at the intended operational sites to deliver the required services with continued operational and cost effectiveness.

3.8.2 Inputs

According to a suitably determined CBS (cost breakdown structure), data related to the operation and maintenance activities of a considered system must be collected. An illustrative CBS is shown thus:

- Operation
  - Personnel
  - Training
  - Infrastructure/Facilities
  - Consumables
  - Others
- Maintenance
  - Personnel
  - Training
  - Facilities
  - Spares
  - Repair Parts
  - Documentation
  - Test and support
  - Infrastructure
  - PHST
  - Modification/Upgrading

Various data formats are used to gather cost and non-cost (e.g. technical) data. Databases which are specifically designed for automated information and reporting systems are examples. More information on the collection of data can be found in Chapter 6. After data is obtained, data analysis and normalisation process must be performed to have a consistent data set (adjustment/normalisation of data).

3.8.3 Outputs

The essential output of in-service phase life cycle cost studies is the gathering of actual costs occurring during the operation and maintenance activities. However, it should be recognised that there will be differences in the expected data due to the approach adopted by the users to maintain the availability of the

system during its life. Care is needed therefore to ensure that the gathered data is correctly interpreted and properly used in any life cycle cost analysis.

3.8.4 Life Cycle Cost Benefits

One of the main objectives of life cycle costing is to provide suitable data in order for the decision makers to forecast future costs, manage existing budgets and undertake options analysis where necessary. The forecasting of future expenditure requires a sound knowledge of the actual in-service costs. Therefore, the collection of actual costs during the in-service phase helps:

- To analyse differences between forecasting and actual costs.
- To help to identify potential areas of cost saving.
- To feed cost databases.
- To identify cost drivers.
- To implement management control.
- To plan to phase out the system and reduce stockholding.

Life cycle cost studies during this phase are also used to achieve the following objectives:

- One of the main objectives of life cycle cost studies is to provide a forecast of future spending on operating and maintenance costs. This will determine the likely financial commitment to support the system in-service.
- Monitoring costs: to identify cost growth and inaccuracies. This can be achieved by comparison between actual cost and earlier estimates. If unpredicted cost growth is identified, more detailed studies that focus on the identified differences has to be undertaken. This is in order to find the reasons behind the unexpected cost growth, it may stem from a different actual utilisation than was used in earlier cost modelling estimates. This is particularly important if a logistic support contract has been awarded with a mechanism of penalties and incentives.
- The life cycle cost studies give operational planning departments the opportunity of estimating the costs of activities to be performed and selecting between them, particularly when activity based approaches for cost control are followed. Therefore, in-service phase costing enables the discard of activities in a cost-effective manner.
- Data collection activities on systems in an operational area supply factual historical data about those systems performance. This data can subsequently be used to support future life cycle costing studies.
- Involvement in a new investment analysis process anytime there is a significant change to the planned in-service programme.
- The in-service life cycle costs also enables staff to address such questions as:
  - Consider a buy or lease option on the services to be provided?
  - Determine the level of stock to be held and where are they best placed?
  - What maintenance operations should be undertaken at the various support organisations?

3.8.5 Types of Life Cycle Cost Studies

The in-service phase gives the cost analyst the opportunity of verifying the estimates with the actual costs. Because of that, the life cycle cost activities during this phase concentrate on the data collection of actual data and information. Data collection processes can be accomplished using manual techniques and/or

automated information/database systems. Some data analysis must be performed in order to prepare the data for use in cost estimating models or cost estimating relationships.

During the in-service phase, studies are performed in order to refine the life cycle cost estimate of the systems in use by using actual recorded data. Further analysis may be done in order to determine the failure rates of a system in use and measure the effects of those failures against the predicted values. Therefore, it is important to capture system related reliability parameters such as MTBF (mean time between failures) and MTTR (mean time to repair) so that the operating and support calculations used in the life cycle costs are properly calculated on an engineering rather than a budget controlled basis.

In addition to the traditional studies conducted during this phase on evaluating cost reduction opportunities, studies on the likely costs and implications on the phasing out of the systems are likely to be conducted. This will include stock reduction and disposal considerations such as scrap, resale or recycle.

3.8.6 Methods Employed

For determination of the in-service phase costs, quantitative expressions of the costs must be specified. It falls into three categories. These are:

- Cost of platform/system life-cycle operation.
- Cost of platform/system life-cycle support.
- Cost of platform/system modifications.

Methods employed during the in-service phase include system dynamics and discrete event simulation to provide predictive outcomes, but also the parametric method is used (see Chapter 4 for details). In order to capture actual costs methods like activity based costing can be used. As activity based costing provides actuals and does not provide any estimates, this methods is not considered in this report. However, both type of methods are complimentary and provide the ability to conduct "what-if? scenarios".

3.8.7 Life Cycle Costing Process

Figure 3-21 provides a simple illustration of the life cycle costing process for this phase. It shows that at this PAPS phase the source data to support the life cycle costing is likely to be the actual costs arising from operating and supporting the system. This information can be used to refine the estimates and provide realistic simulation of future spending patterns. The cost breakdown structure should now be fully populated to provide a comprehensive view of the life cycle costs.

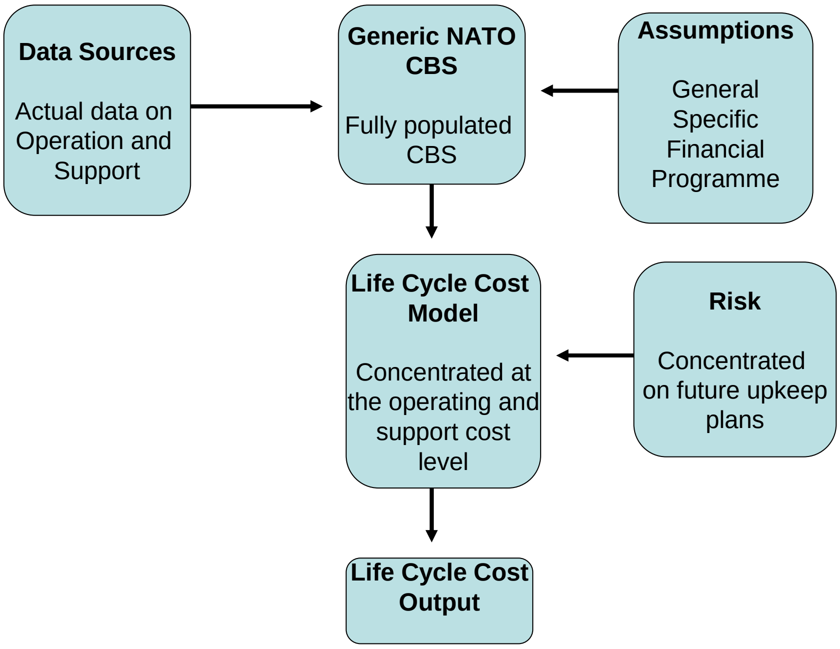


Figure 3-21: Simplified In-Service Phase Life Cycle Costing Process.

Life cycle cost studies will concentrate on future upkeep or upgrade plans as well as providing future cost spending profiles.

Any risk analysis activity at this phase will concentrate on future support plans such as alternative support solutions or planned upkeep/update programmes. As previously, these risks would be captured and recorded in a risk register and analysed with respect to the effect on future planning.

During this phase the life cycle cost output should mirror that of the actual expenditure. The output will therefore be used for future budgeting and feedback to support analysis on improving the estimating capability and the forecasting of future systems. In summary, the key considerations to the life cycle costing process for this phase are:

- The principal data sources are likely to be the actual costs incurred in the operation and support of the equipment. This can then be measured against the planned budget and use of the equipment.
- The reliability, availability and maintainability targets can be analysed against the actual effort incurred. This will provide a basis for adjusting the supportability plans.
- The life cycle costing activities are likely to be conducted using detailed cost analysis models concentrating on the operation and support functions.
- There will be very few assumptions to be recorded and assessed. Previous assumptions will have been superseded by actual data. However, financial assumptions on future escalation, exchange rates, etc., will still be made.

3.8.8 Risk Assessment

The risk assessment during the in-service phase will more likely support any studies of alternative support scenarios. The principles and practice discussed earlier are still valid for this phase. Care will be needed however, to counter any over-optimistic predictions when comparing the alternative solutions. It would be unwise to introduce any risk into an in-service programme without a comprehensive analysis of the possible outcome.

3.8.9 Example

ABC (Activity Based Costing) is a good example of an in-service life cycle cost study for determining actual costs.

ABC is an accounting technique that determines the actual cost associated with products and services produced by an organisation without regard to the organisational structure. The method has its roots in the manufacturing sector and was developed as a model to identify activities that add value and those which are non-added value with the aim of removing waste.

Activities can be defined as a named process, function or task that occurs over time and has a recognised result. Activities use up assigned resources to produce services or products for life cycle costing. These can be activities such as repair of equipment, training personnel, and in some cases a combination of military activities**.**

The system requires a high level of investment in developing recording schemes and element definitions.

Cost analyses are performed using an in-house model named Educational Cost Effectiveness Analysis Model (EDCAM). The interface and menu components of the model are illustrated in Figure 3-22. As shown in the figure, the model requires resources, activities, products and the allocation of resources and activities to activities and products reciprocally to be defined. The main output of the model is the cost of any defined activity based on the resources used, and the product total costs. The model also includes an effectiveness estimation module which works on multi-criteria basis. The functional capabilities of the model enable the educational planners to select the most cost-effective training programmes.

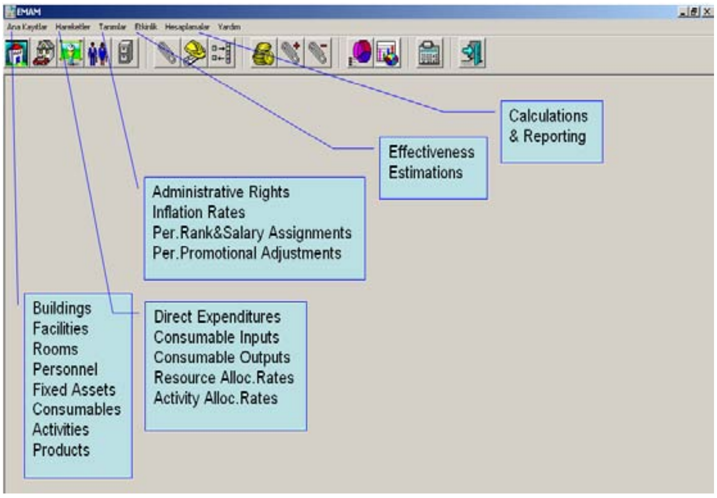


Figure 3-22: The Interface and Menu Components of EDCAM.

3.8.10 References

[31] RTO-TR-058 “Cost Structure and Life Cycle Costs for Military Systems” Technical Report.

[32] Turkish Armed Forces Logistics Concept.

[33] Turkish Navy ILS Guide.

[34] www.ams.mod.uk

[35] FAA Life Cycle Cost Estimating Handbook, Investment Cost Analysis Branch ASD-410, June 3, 2002.

3.9 NATIONAL DISENGAGEMENT

3.9.1 Summary Definition of Phase

This phase starts with a NADI (National Disengagement Intention). The NADI is a statement of a decision to withdraw equipment from operational utilisation, including forecast dates, quantities and other relevant information such as age, condition of equipment, and availability of spare parts.

However, in some NATO nations, cost estimates for this phase are conducted in the project definition phase. The estimates for the likely disengagement cost are required at the early phases in order to meet the needs of a government accounting practice whereby a funding provision (included in the life cycle cost estimate) accrues annually over the project's life to equal the value of the predicted financial liability at the end of the programme's life.

This difference of opinion (do it first – leave it till later) has caused some confusion with respect to what should be included in the life cycle costing boundary and when the cost estimates for this phase are best conducted.

For nuclear and other dangerous substances then it is clear that an estimate of the likely disposal costs should be included in the early life cycle costing analysis. For other substances where the likely financial liabilities are lower then it may be more appropriate to assess these costs at a later stage in the programme.

The following sub-sections present the view that cost estimates for this phase will be conducted at the Project Definition phase and will support an impact assessment using PESTEL (Political, Economic, Social, Technological, Environmental and Legal) analysis[6] or other similar techniques.

3.9.2 Inputs

For a preliminary assessment three primary criteria (viability, socio-political considerations and finance aspects) are defined, each of which will require evaluation on a range of issues. Examples of the criteria normally include:

- **Viability** to cover the following issues:
  - Technical feasibility.
  - Environmental Impact (technical considerations).
  - Legislation/Regulation.
  - Flexibility to change.
  - Time sensitivity.

- **Socio-political** considerations:
  - Response from Pressure Groups.
  - Public Acceptability/Concerns.
  - Acceptability to Parliamentary Groups.
  - Environmental Impact (site).

[6] PESTEL: **P**olitical factors, **E**conomic factors, **S**ocial factors, **T**echnological factors, **E**nvironmental factors, **L**egal factors. For each set of factors, you need to evaluate what is the situation and what developments are likely to take place in the next future.

  - Alignment with Government policy.
  - Alignment with International policy.
  - Historical acceptability.
  - Physical security constraints.

- **Financial** aspects including:
  - Overall cost.
  - Commitment and spend profile.
  - Risk of extra cost materialising.
  - Affordability.

3.9.3 Outputs

Each of these would have an associated critical success factor and the disposal options can then be measured and evaluated.

3.9.4 Life Cycle Cost Benefits

The long term plan should include the identification and consideration of a number of disposal options. By conducting life cycle cost analysis the following options can be assessed:

- Re-deployment (can the equipment be used for training/instructional use, as a heritage/museum asset, for spare recovery, etc.).
- Reclamation, recycling, re-manufacture (is there a possible other use as opposed to disposal).
- Sale (potential customers).
- Disposal at cost.

3.9.5 Types of Life Cycle Cost Studies

Some nations are conducting cost studies and developing estimates of the likely disposal costs during the concept and feasibility phases in order to inform and make budget provisions. The types of costing studies being conducted at this early phase are predominantly restricted to high-level estimates to support disposal option analysis and financial liability studies. In this instance, the life cycle cost would be one of the criteria measures in a rigorous assessment of the alternative options. For larger programmes where a PESTEL analysis is conducted at a later stage then the life cycle costing study would support the financial aspects taking cognisance of the results from the other measurement criteria.

3.9.6 Methods Employed

Predicting cost estimates for equipment disposal is not dissimilar to the methods employed at the pre-feasibility phase. The most common methods of estimating the likely disposal cost currently used is by analogy and parametric. These methods are well established and can calculate the negative and positive financial impact depending on the alternative disposal options being assessed. However, care should be exercised when employing both methods. To avoid error, it is essential that as much historical data as possible is gathered and evaluated to provide a degree of ‘normalisation’ such that a ‘like for like’ basis is achieved.

3.9.7 Life Cycle Costing Process

Figure 3-23 provides a simple illustration of the life cycle costing process. It shows that at this PAPS phase the source data to support the life cycle costing is likely to be immature therefore a greater reliance on the types of data sources indicated should be expected. In addition, there will be a high level of assumptions in terms of the likely performance/design parameters of the systems being evaluated. Risk is likely to be qualitative rather than quantitative.

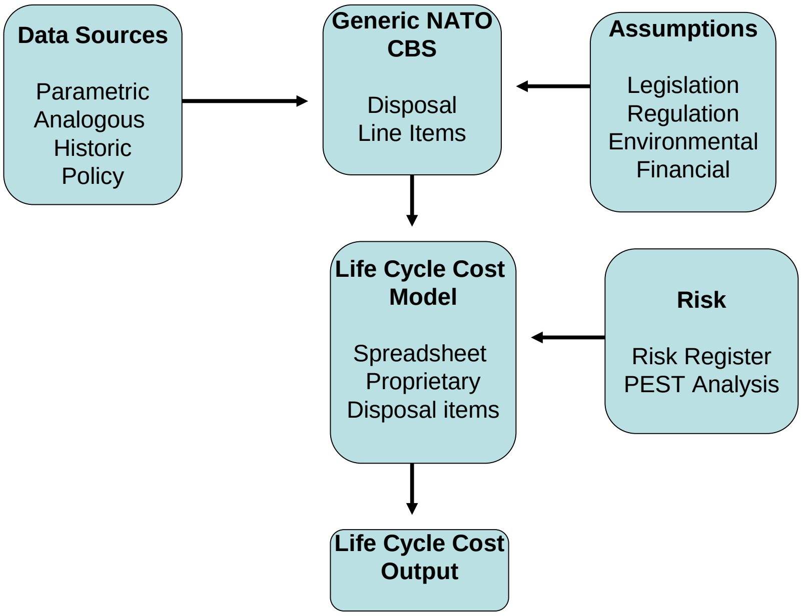


Figure 3-23: Simplified Disengagement Phase Life Cycle Costing Process.

It should be expected therefore that the life cycle cost output for the disengagement phase will be an understanding of the programme liability costs and the level of uncertainty surrounding them. In summary, the key considerations to the life cycle costing process for this phase are:

- The principal data sources are likely to be parametric based and for speed and ease of use a proprietary cost estimating model is likely to be employed.
- There will be many assumptions to be recorded and assessed.
- The risk will be measured at the very top level probably utilising some high level risk register and PESTEL techniques.
- The disposal phase costs are likely to be in the form of rough order of magnitude determined by legislation, regulation and market forces at the time.

3.9.8 Risk Assessment

The identification of risk for this phase will be conducted at a very high level. It is likely to be a combination of single line statements and will probably contain a mixture of issues as well as risks. The cost analyst will need to distinguish the difference between them in order to ensure that only those applicable risks are to be included in the cost estimate.

Where there is no risk register or risk record then another approach would be to employ an optimism bias technique. Here it could be employed to redress overly optimistic tendencies by making empirically based adjustments to the cost estimates (this technique is explained at Chapter 7).

At the very minimum, the life cycle cost estimate produced at this phase should include or indicate the level of financial risk exposure and liabilities.

3.9.9 Example

There are significant benefits and cost saving opportunities to be realised by reducing asset holdings. Current approaches include the use of marketing arrangements to examine the most cost effective disposal method.

The principal means of gaining a return on surplus inventory is either by scrap or sale. By definition, any surplus equipment or stores (excluding nuclear) will have been written off by the user organisation and therefore, in theory, are only worth their scrap value. In practice, they are a source of affordable and proven defence equipment for other countries and can provide the organisation with an additional source of income to offset any future spending.

As the costs of disposal is therefore determined by the market forces and opportunities at the time then the financial aspects of the PESTEL criteria should reflect the implication and cost associated with scrap value only.

During the in-service phase further opportunities such as re-deployment or sale may arise. These should be seen as an opportunity. A full cost benefit analysis (see Sub-section 3.3.9.2) should then be undertaken to support the decision process.

3.9.10 References

[36] Middleton, J., "The Ultimate Strategy Library", Capstone Reference.

[37] UK MoD, Operational Analysis – Foundation for the Business Case, November 2003, Director General (Scrutiny and Analysis) [unpublished MoD Documents/Reports].

[38] www.ams.mod.uk

3.10 NATO POLICY FOR SYSTEMS LIFE CYCLE MANAGEMENT AND THE FUTURE OF PAPS

3.10.1 General Comment

As stated previously, the PAPS life cycle phases have been adopted in this report because they represent a commonly accepted NATO standard. Furthermore, they are reasonably well defined and they form a natural framework for extending the process descriptions and guidelines given in PAPS to include costing activities.

It is recognised by the authors of this report, however, that while the subject and purpose of PAPS remains as relevant as ever, the document itself, though still in effect, is dated. Many references to NATO documents, agencies, etc., are no longer relevant. More importantly, NATO policy has evolved. NATO policy for standardisation now calls for the use of civil standards to the maximum practicable extent. Such a standard was published in 2002 as ISO 15288 on system life cycle processes. This standard has been adopted in NATO policy for SLCM (systems life cycle management).

At the time of writing this report, a working group under AC/327 NATO LCMG (life cycle management group) is working to update PAPS to comply with NATO policy for SLCM and the related AAP-48

on NATO life cycle stages and processes, which is a guide to implementing NATO policy for SLCM. (AAP-48 is, at the time of the writing of this report, in the draft stage.)

While it is therefore likely that the PAPS will be adapted to comply with ISO 15288, the original PAPS life cycle phase definitions are retained in this report. The rationale behind this is that the present definition is still NATO practice and that the focus of the original PAPS on the early part of the life cycle is more in line with objectives of this report.

ISO 15288 divides the system life cycle into six stages, defined later in this chapter, as opposed to the eight phases of the original PAPS. The main difference between them is that PAPS treats the earliest part of the life cycle in more detail, while ISO 15288 divides the in-service activities into utilisation and support activities. Note that mission need evaluation, the first phase of the PAPS life cycle model, is not considered part of the system life cycle in ISO 15288. A rough translation between the original PAPS life cycle phases and the ISO 15288 life cycle stages is provided in Figure 3-24.

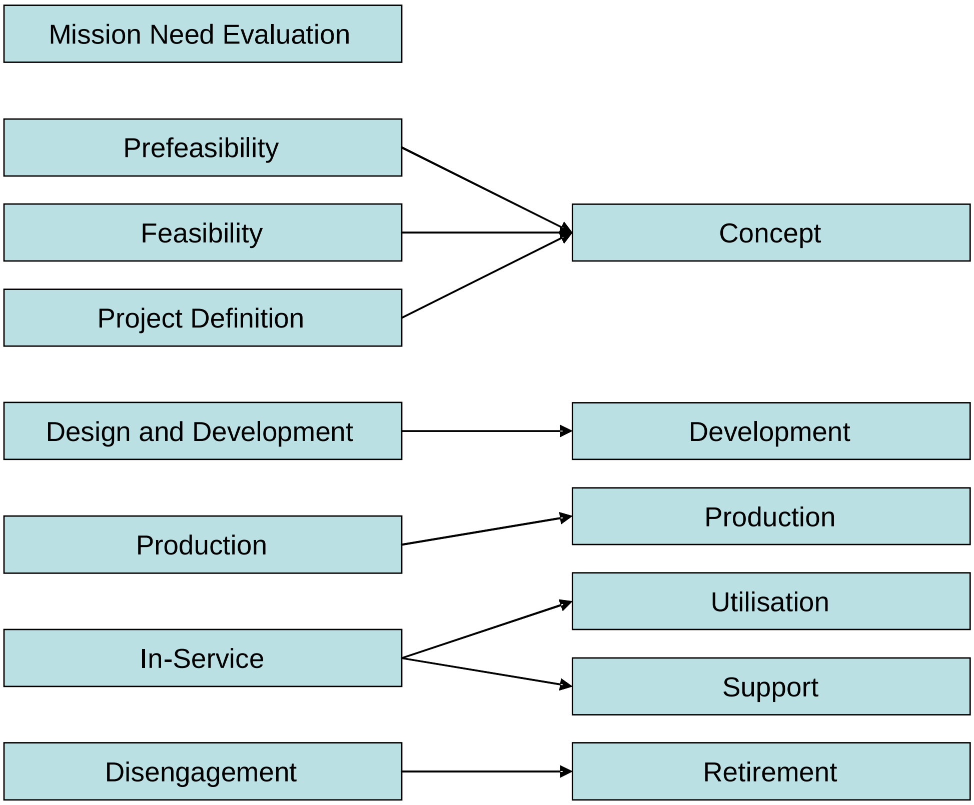


Figure 3-24: "Translation" from PAPS Phases to ISO 15288 Stages.

3.10.2 ISO 15288 Life Cycle Stage Definitions

AAP-48, NATO life cycle stages and processes is based on ISO 15288. The stages defined in AAP-48 are the same as those included in ISO 15288 AAP-48. The following definitions are therefore taken from AAP-48.

3.10.2.1 Concept Stage

The concept stage starts after the decision to fill a capability gap with a materiel solution and ends with the requirements specification for this materiel solution. The purpose is to evaluate the relative need, potential

risks, and cost benefit of a proposed system, or a major upgrade of an existing system prior to any commitment of resources. One or more alternative solutions to meet the identified need or concept are developed through analysis, feasibility evaluations, estimation (such as cost, schedule, market intelligence and logistics), trade-off studies, and experimental or prototype development and demonstration.

3.10.2.2 Development Stage

The development stage is executed to develop a SOI (system of interest) that meets user requirements and can be produced, tested, evaluated, operated, supported and retired. This stage also ensures that the aspects of future stages (production, utilisation, support, and retirement) are considered and incorporated into the design through the involvement of all stakeholders.

3.10.2.3 Production Stage

The production stage is executed to produce or manufacture the product, to test the product and to produce related supporting and enabling systems as needed.

3.10.2.4 Utilisation Stage

The utilisation stage is executed to operate the product at the intended operational sites to deliver the required services with continued operational and cost effectiveness. This stage ends when the SOI is taken out of service.

3.10.2.5 Support Stage

The support stage is executed to provide logistics, maintenance, and support services that enable continued SOI operation and a sustainable service. The support stage is completed with the retirement of the SOI and termination of support services.

3.10.2.6 Retirement Stage

The retirement stage provides for the removal of a SOI and related operational and support services and to operate and support the retirement system itself. This stage begins when a SOI is taken out of service.

3.10.3 References

[39] NATO International Staff – Defence Support Division, Allied Administrative Publication (AAP) – 20 – Handbook on the Phased Armaments Programming System (PAPS), February 1989.

[40] C-M(2000)54 – NATO Policy for Standardization, 20 September 2000.

[41] ISO/IEC (International Standards Organisation/International Electrotechnical Commission) 15288 “Systems Engineering – System Life Cycle Processes”, 1 November 2002.

[42] C-M(2005) 0108-AS1 – NATO Policy for Systems Life Cycle Management, January 2006.

[43] PFP(AC/327)D2006(0009) – Allied Administrative Publication (AAP) – 48 – on NATO System Life Cycle Stages and Processes (Draft Edition 1), February 2006.

Chapter 4 – METHODS

4.1 GENERAL

This chapter discusses the different methods of generating life cycle cost estimates and conducting cost analyses at various stages in the NATO PAPS cycle. It is not meant to be a prescriptive description of the methods which are best found by accessing the reference books and web sites but does provide guidance on the appropriate approaches to life cycle costing for each PAPS phase.

4.2 OVERVIEW OF METHODS

Most cost estimates require the use of a variety of methods. A different approach may be used for each area of the estimate so that the total system methodology represents a combination of methods. Sometimes a second method may be used to validate the estimate.

When choosing an estimating method, the cost estimator must always remember that cost estimating is a forecast of future costs based on a logical interpretation of available data. Therefore, availability of data will be a major factor in the estimator's choice of estimating methodology.

The best combination of estimating methods is the one which makes the best possible use of the most recent and applicable historical data and systems description information and which follows sound logic to extrapolate from historical cost data to estimated costs for future activities.

An example of this is would be to use data gathered through expert opinion combined with methods for simulation to obtain reliable data to conduct simulations on different support organisations. Linear programming might then be used to optimise a spares inventory for the chosen support organisation. These values can then be used in the parametric techniques employed in estimating the total life cycle costs for the programme.

The following table shows how the methods have been categorised for easy reference.

Table 4-1: Method Categorisation

Method Category	**Methods**
Optimisation	Linear programming Heuristics
Simulation	System Dynamics Discrete Event Monte Carlo
Calculation/Estimation	Analogy Parametric Bayesian Engineering Catalogue Rule of Thumb Expert Opinion
Decision Support	Analytical Hierarchy Process Multi-Criteria Decision Analysis

4.2.1 Optimisation Methods

Mathematical programming and heuristics are both common forms of optimisation methods. Linear programming is a subset of mathematical programming but deemed important enough to be described separately.

4.2.1.1 Linear Programming

Linear programming is a mathematical modelling technique designed to optimise the usage of limited resources. The usefulness of this technique is enhanced by the availability of highly efficient computer codes. A linear programming model consists of three basic elements:

- Decision variables that need to be determined.
- Objective (goal) that need to be optimised.
- Constraints that need to be satisfied.

Linear programming is particularly useful for large and medium scale problems in which there are many variables and many constraints to be considered. Therefore, the use of linear programming is often supported by computer software.

4.2.1.2 Heuristics

Methods based on heuristic approaches use standardised rules of thumb repeated many times in order to find a good enough solution to a problem. These types of models can be easier to apply than the mathematical programming methods. There are, one the other hand, no guarantees that the solutions found will be the optimal choices for solving the problem.

4.2.2 Simulation Methods

System dynamics and discrete event simulation are both forms of simulation models that allow a representation of the activities of a system over time. In each case, the simulations step through time and perform calculations for that point in time which will change the state of the system in some way. The end state at one point in time is the start state for the next.

4.2.2.1 System Dynamics

System dynamics works by using even time steps. It keeps track of how many items are in particular locations (stocks) in the system (items can be entities such as people, cash or can represent fluids). It works by allowing flow into and out of stocks through valves. The structure of the model allows the development of behaviour to control the flows, and to provide measures based on the state of the system (such as costs). One of the most powerful features of system dynamics is the visual structure of the model that helps users and developers to understand the relationships between elements of the model. This structure allows the representation of complex behaviour while using comparatively simple equations for each relationship.

System dynamics are usually good for building models with a wide scope and long run behaviours. They are generally quicker to build than discrete event simulations and also execute more quickly. The models do not usually contain stochastic elements although they can be repeatedly run with different input values to examine uncertainty around inputs. System dynamics models are good for life cycle costing where there can be a wide scope for cost drivers, large numbers of items and long duration.

4.2.2.2 Discrete Event Simulation

Discrete event simulation uses uneven steps in time with the model jumping to the point in time where the next event will occur. The event will cause a change in state of the system that can trigger other events to occur immediately and/or schedule another event to occur at a point in the future. The model keeps track of every entity in the system in terms of location and can store characteristics of each entity. Many of the models have animations that show the state of the system, although much of the actual logic is hidden below the surface of the model.

Discrete event simulation is good for building models with a narrow scope and relatively short-term durations. They generally take longer to build than system dynamics models and execute more slowly because each of the entities is represented individually. The model allows stochastic elements, using sampling from probability distributions to represent things like inter-arrival times and durations of activities. Due to the stochastic elements in the models, all experiments should make use of multiple runs in order to calculate means and standard deviations for the key output variables. Discrete event simulation is good for logistics models where it is important to understand how the system can deal with peaks and troughs in demand.

4.2.2.3 Monte Carlo Simulation

Monte Carlo simulation is used in defence cost analysis to generate frequency or probability distributions which are otherwise too difficult or impossible to generate mathematically, that is, using formulae. More specifically, all variables in a cost estimating model potentially affected by risk and uncertainty are first identified. Then, probability distributions are estimated or selected for each. This entails first choosing the type of distribution to apply and then estimating the distribution's parameters. Possible distribution types include:

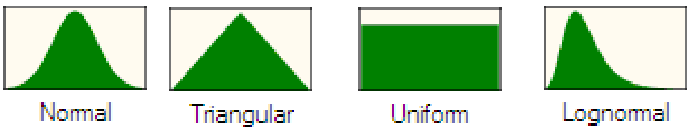


Figure 4-1: Example of Typical Distribution Types.

Monte Carlo simulation generates random values for each of the uncertain variables over and over again, according to the type of distribution chosen, to produce a frequency or probability distribution of total costs for a weapon system or automated information system acquisition programme. Figure 4-2 shows a typical Monte Carlo output, based on 5000 selections or trials.

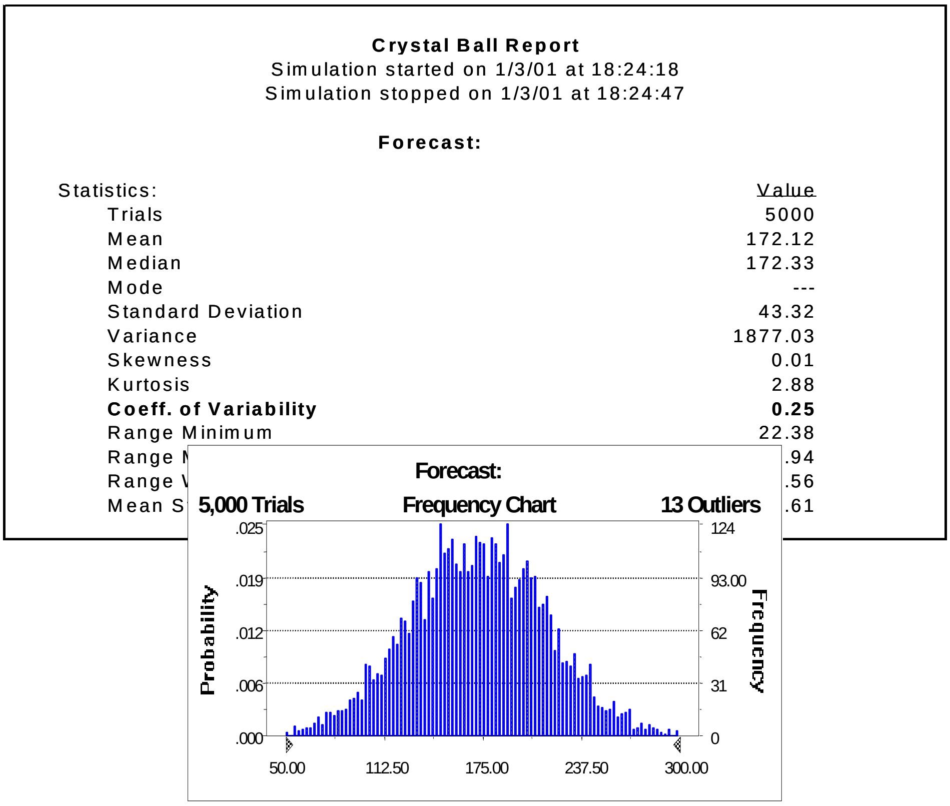


Figure 4-2: Example of Monte Carlo Output.

4.2.3 Calculation/Estimation Methods

4.2.3.1 Analogy

The analogous or comparative method assumes that no new programme represents a totally new system. Most new programmes originate or are evolved from already existing or simply represent a new combination of existing components.

The analogous method compares a new system with one or more existing systems for which there are accurate cost and technical data. The historic system should be of similar size, complexity and scope. The estimator/analyst makes a subjective evaluation of the differences between the new system of interest and historic systems. Normally, engineers are asked to make the technical evaluation of the differences between the systems. Based on the engineer's evaluation, the cost estimator/analyst must assess the cost impact of the technical differences.

It is not necessary to compare the new system to just one other analogous system. It may be desirable to compare some sub-systems of the new system to sub-systems of old system A, and other to sub-systems of old system B.

The advantage of the analogy method is that if a good analogy can be found, it allows for a lower level of detail, thus enhancing the credibility of the estimate.

The estimator should be cautious of using this technique without fully understanding the basis and the proper usage context. The major disadvantage of the analogy method is that it can be difficult to find a good analogy and the required engineering judgment.

An example of this method can be found at Sub-section 3.5.9.1.

4.2.3.2 Parametric

The parametric method estimates costs based upon various characteristics or measurable attributes of the system, hardware and software being estimated. It depends upon the existence of a causal relationship between system costs and these parameters. Such relationships, known as CERs (cost estimating relationships), are typically estimated from historical data using statistical techniques. If such a relationship can be established, the CER will capture the relationship in mathematical terms relating cost as the dependent variable to one or more independent variables. Examples would be estimating costs as a function of such parameters as equipment weight, vehicle payload or maximum speed, number of units to be produced or number of software lines of code to be written. The CER describes how a product's physical, performance and programmatic characteristics affect its cost and schedule.

The parametric or statistical method uses regression analysis of a database of similar systems to develop the CERs. Therefore parametrics rely on complex relationships and therefore require a considerable amount of data to accurately calibrate. Some of the commercially available cost estimating models do have historic public domain information attached and this enables the model to achieve reasonable results in the early phases of the procurement cycle when capability is known, but detailed requirements are poorly defined.

Parametric estimating is used widely in government and industry because it can easily be used to evaluate the cost effects of changes in design, performance, and programme characteristics. The major advantage of the parametric method is that it can capture major portions of an estimate quickly and with limited information. Parametric cost estimating, in essence, is usually a form of hedonistic regression analysis. More specifically, the cost of a weapon system, or component thereof, is typically postulated as a function of the technical, performance, and programmatic characteristics of that system. There are several advantages of this cost estimating technique:

- **Objectivity.** The cost-estimating relationship, ideally, is based on consistent, quantitative, non-subjective inputs, or values of the dependent and explanatory variables.
- **Ease of Use.** Values of cost, the dependent variable, can be easily calculated based on changes to any of the explanatory variables. This is useful for what-if, sensitivity analyses.
- **Tests of validity.** Standard outputs of regression analysis include F and t statistics which measure, respectively, the overall power of the set of explanatory variables in explaining changes in costs and of the significance of any one variable in explaining changes in costs.

A critical consideration in parametric cost estimating is the similarity of the systems in the underlying database, both to each other and to the system which is being estimated. Additionally, the database must be homogenous. A data element entry for one system must be consistent with the same data element entry for every other system included in the database. The major disadvantage of the parametric method is that it may not provide low level visibility and subtle changes in sub-elements cannot be reflected in the estimate easily.

An example of this method can be found at Sub-section 3.5.9.2.

4.2.3.3 Bayesian Techniques

Bayesian techniques deal with how a prior belief should be modified in the light of additional information e.g. later information or information from another source. A parameter to be estimated is known, on the basis of information available at the time, to have a certain value subject, since that information is

incomplete or of a probabilistic character, to a range of uncertainty i.e. there is a "prior probability distribution" of that parameter. Further information then becomes available which, of itself, suggests a different value and probability distribution for the parameter. Bayesian inference allows these two sets of data to be combined to give the most probable value (and least uncertainty) for the parameter in question i.e. the correct "posterior distribution".

Beliefs are expressed either as the probabilities of a finite number of discrete outcomes of a future event or else, as here, as the probability distribution of a continuous variable. The question to be answered becomes, therefore, that of how an initial estimate (the 'prior' distribution) is best modified in the light of additional information so as to obtain a refined estimate (the 'posterior' distribution).

Figure 4-3 presents the relationship between the inputs and outputs and shows how the cost estimates can be based on that which is known with some certainty and not on what can only be conjectured at the time the estimates are made. The approach also provides performance-based estimates from the earliest stage of the project life cycle and allows more precise design-based estimates to be derived as proven design data becomes available.

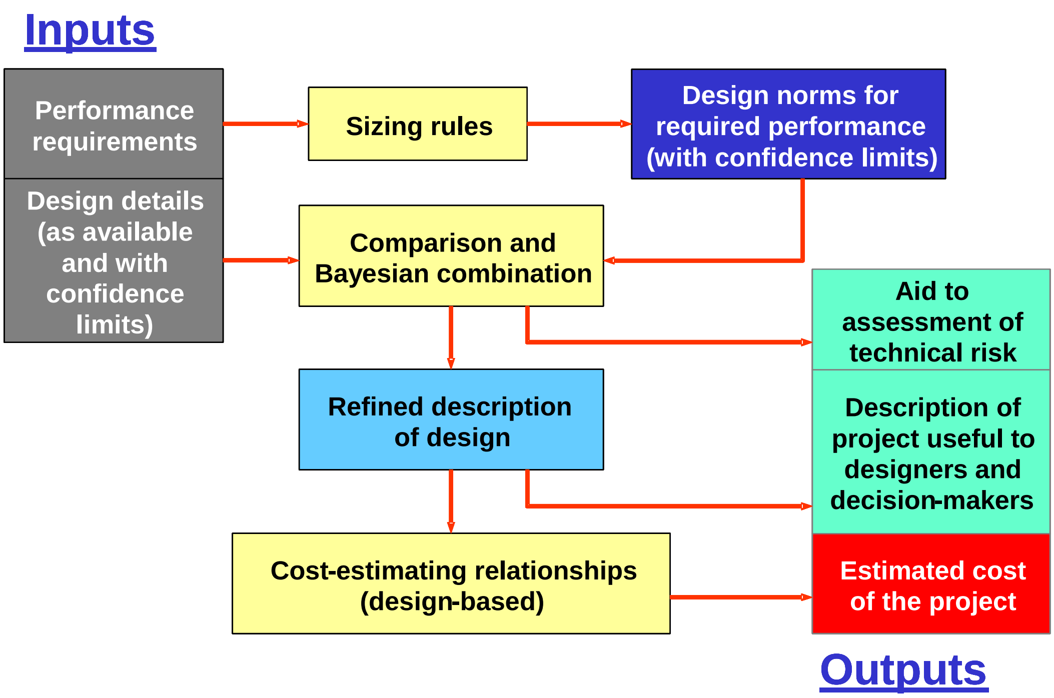


Figure 4-3: Bayesian Application to Cost Estimating.

Within the context of the techniques described above, such questions arise from design variables (on which the cost estimates are later to be based) being both supplied by the estimator and also derived within the model from the performance required of the equipment whose costs are to be estimated, as also input by the estimator. How this is done may be illustrated through an example.

Suppose that the estimator has supplied an estimate of the displacement of a ship as to be 10,000 ± 3,000 tons. This is the initial estimate i.e. the 'prior' distribution of displacement. The estimator has also supplied information concerning the performance required of the vessel in question. From that, the model computes, as a design norm, a displacement of 12,000 ± 4,000 tons.

It is now necessary to examine the compatibility of these two estimates.

In this case, the two estimates of displacement do not conflict. Rather, there is a high probability that they are both estimates of the same quantity i.e. of what will be the displacement of the vessel when designed fully and built. The question at issue becomes then what value of displacement should be used for the purposes of estimating the cost of this ship i.e. what ‘posterior distribution should be taken forward into the next stages of the calculation.

There are various possibilities. They are:

(a) To use the estimate of displacement provided by the model i.e. that of 12,000 ± 4,000 tons;

(b) To use the estimate input by the estimator i.e. that of 10,000 ± 3,000 tons;

(c) To average the two estimates; or

(d) To combine the two estimates but to weight each according to its reliability as manifest by the uncertainty attached to each.

Clearly, the first approach (a) is incorrect since it concentrates solely on the estimate of lesser certainty and ignores that which is more certain.

The second approach (b) is more reasonable but unsatisfactory. The higher estimate is only somewhat less certain and it is inappropriate, therefore, to ignore entirely the indication given by the model that the displacement may well turn out to be higher than is supposed at present.

The third possibility (c) is yet more reasonable but it is still to be criticised. To average the two estimates (obtaining, thereby, a figure of 11,000 ± 2,500 tons) is to attach equal weight to both even though one is less certain than the other.

The fourth (d) (and Bayesian) approach is optimal. Weights attached to each estimate are those, which minimise uncertainty of the combined estimate and, so, make best use of all of the information available.

Details of the mathematics involved are not repeated here. However, the reader may gain an understanding of their basis by regarding each estimate as being (independently and hypothetically) the result of repeated sampling from the same (infinite) population comprising all possible values for, in this case, the displacement of the vessel in question. The estimate having the greater certainty is then the result of averaging more samples than was the case for the result having the lesser certainty. Accordingly the former is accorded more weight when all of the samples are pooled and a grand average computed.

In the present example the result of this Bayesian approach is an estimate of displacement of 10,720 ± 2,400 tons. Note that, as expected and as is reasonable, this inclines somewhat more to the more precise of the estimates being combined than their simple average. Note also that the uncertainty of this estimate is somewhat less than that resulting from simple averaging, again reflecting optimal use of all of the information available.

The utility of this approach may be illustrated further by considering the evolution of a project. At its earliest stages, prior to any design or development work, estimates of design characteristics, supplied by the estimator cannot be anything but imprecise. Through the Bayesian approach, the model will then rely upon the (the more certain) design norms, which it generates. As design and development proceed more certain information will become available to the estimator for input to the model and estimates will be based progressively more upon such data. When design and development are complete design characteristics will be known exactly. The model will then rely upon those alone thus a single model is able to respond appropriately, optimally and automatically to all of the circumstances encountered throughout the evolution of a project.

4.2.3.4 Engineering (bottom up)

The engineering or bottom up method of cost analysis is the most detailed of all the techniques and the most costly to implement. This technique starts at the lowest level of definable work within in the cost breakdown structure and builds up to a total cost. This type of estimate is used when detailed design data is available on the system. Two types of engineering estimates can be distinguished:

- An engineering estimate provided by a contractor. Making sure that the contractor has provided all the data and supporting information to clearly define the basis of the estimate.
- An engineering estimate provided by government personnel (an in-house prepared engineering estimate).

Engineering estimates prepared by contractors differ substantially from engineering estimates performed by government in at least two ways. First, the contractor prepared estimate is based on input from work units that will do the work and that have performed similar work in the past. Second, contractors are able to bring more detailed programme description data to the cost estimating process. For an engineering estimate provided by a contractor, an industrial engineer will estimate the labour hours, raw materials and parts required to complete the work. The industrial engineer may use a variety of techniques in estimating the direct labour and material cost of each discrete work element.

An engineering estimate prepared by a contractor do not usually include such elements as other government costs (e.g. other system and sub-system integration costs). It is also important to ensure that any engineering change costs are included in the government budget estimate submissions.

A contractor prepared engineering estimate will be used or evaluated by a government cost estimator. The following guidelines have proven useful in the past with respect to evaluating contractor prepared engineering estimates:

- Quickly find out the high cost areas or items and focus attention on them.
- If the evaluation is part of a source selection compare costs among contractors to spot unusually high or low costs for further investigation.
- If in time more than one cost estimate has been provided by the contractor see whether major changes were made to the cost estimate.
- Use audit report to check the validity of the rate and factors used by the contractor.
- In high cost areas, make sure the contractor has provided all substantiating information requested to generate a cost estimate.

Perhaps the most important guidance here is to require the contractor to submit cost data and substantiating information in a format that is clear, complete and ready for evaluation. The NATO generic cost breakdown structure developed by SAS-028 may help here.

In-house engineering estimates are mainly prepared to forecast out year cost for new systems. Government cost estimators usually obtain the necessary data through visits to and discussion with the prime contractors.

In-house engineering cost estimates differ from contractor prepared engineering cost estimates in several ways. For an in-house estimate fewer estimators, specialists and less information is available, especially when prior to production, when not much actual data is available. When the programme is in production, the differences should not be so significant.

The engineering cost estimate is most often used during the production an deployment phase. This technique encourages the contractor to do his homework early on and define all the work down to the lowest level of the cost breakdown structure.

4.2.3.5 Catalogue or Handbook Estimates

Handbooks, catalogues and other reference books are published that contain lists of off-the-shelf or standard items with price lists or labour estimates. The estimator can use these catalogue prices directly as unit values for standard components within a larger system.

4.2.3.6 Rules of Thumb

These refer to simple usually deterministic cost relationships. They are developed from an analysis of existing cost information.

Any rules developed should only be used at the early stages of project when actual specification and requirements are poorly defined.

4.2.3.7 Expert Opinion

An expert opinion may be used, when data required to use other techniques is not available. It is a judgemental estimate performed by an expert in the area to be estimated. Several specialists can be consulted until a consensus cost estimate is established. Surveying a number of experts independently to reach a consensus of opinion, the Delphi technique also may be used to provide a collective opinion.

An expert opinion can also be used to validate an estimate.

4.2.4 Decision Support Methods

4.2.4.1 Analytical Hierarchy Process

In grading or ordering the importance of a number of items in defence decision making, such as lists of operational tasks or lists of strategic requirements, Kenneth Arrow's "Impossibility Theorem" comes into play.[1] In a nutshell, the theorem indicates that no analytical technique exists that will simultaneously satisfy all commonly regarded fairness criteria in rank-ordering items in a list. Literally dozens of techniques for ordering preferences have been developed over the ages. These include the method of pairwise comparisons (used universally in the defence and commercial sectors), Borda's procedure (used by major league baseball in the U.S. for yearly selection of its most valuable player), and Tukey's algorithm, to name just a few. All techniques, however, as Arrow demonstrated, fall short of perfection.

Nevertheless, the demand for making selections and for ordering preferences remains unlimited. Hence, it is important to choose a method of ordering with good, robust statistical properties, such as those indicated above or below, realising, of course, that no technique is perfect.

The Analytic Hierarchy Process (see also 'Saaty Method'[2]) process is known as a soft operational research approach to quantify how important a criterion is compared to other criterion. This enables acquisition decisions to be approached using an auditable method that considers the importance of all the options against specific subjective and objective acquisition requirements.

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[1] Arrow co-shared the Nobel Prize in Economics in 1972 for this work, which was first undertaken in his Ph.D. dissertation a couple of decades earlier.

[2] The concept of AHP was developed, amongst other theories, by Thomas Saaty, an American mathematician working at the University of Pittsburgh.

It is used when making complex decisions involving many criteria. The process is particularly useful when conducting portfolio and options analysis. Some of the more complex models can provide a three dimensional view of the performance, cost and time aspects and present a graphical as well as a tabular output.

As the technique requires subjective judgement it is recommended that the process of allocating weightings and scorings should involve a team to avoid bias selections from any individual.

4.2.4.2 Multi-Criteria Decision Analysis

MCDA (Multi-Criteria Decision Analysis) is an established operational research technique with wide applicability. For example, in the UK, MACE (Multi-Attribute Choice Elucidation) is an adaptation of MCDA. It is a method for applying objective measurement to the relative merits of mutually exclusive acquisition options. Its principal application is in the assessment of bidder responses to tenders. The application of MACE should be focussed on the offer being made by a bidder. In certain circumstances investment appraisal may also play a part in the tender option assessment.

MACE translates key issues from the requirements for the options to be considered into logical items known as criteria. For each criterion MACE derives a numerical worth. The intermediate result is an assessment hierarchy of clearly defined and measurable criteria which is included in the RFI/ITT. Typically, each key user requirement in a NATO staff requirement is a candidate criterion.

Options are objectively marked against the criterion. Individual criterion marks are transformed and aggregated to produce numerical overall merit(s) for each option. The overall, and intermediate, merits are compared across the options, so informing the selection process.

MACE provides a methodical, objective, value adding, defensible and auditable assessment method, but it is only an aid to the decision making process. MACE may not always unambiguously isolate the best option, but when it does not it will provide reliable information to inform and support option selection. The ultimate decision on which option is to be selected is dependent on many factors, possibly including assessments using other methods. The factors (e.g. technical, commercial, financial, programme/risk management) to be included within a MACE assessment are determined on a case-by-case basis.

4.2.5 References

[44] Pidd, M. (1996), Tools for Thinking, John Wiley & Sons Ltd.

[45] Taha, H.A. (1997), Operations Research, Prentice-Hall International.

[46] www.oscamtools.com (application of System Dynamics with tutorials).

[47] Sterman, J.D., ‘Business Dynamics: Systems Thinking and Modelling for a Complex World’, McGraw Hill, 2000.

[48] Robinson, S., Simulation: The Practice of Model Development and Use, John Wiley & Sons, 2004.

[49] Making Hard Decisions: An Introduction to Decision Analysis, Robert T. Clemen, Fuqua School of Business-Duke University, Duxbury Press; 1996; p. 412.

[50] DoD 5000.4M Cost Analysis Guidance and Procedures, December 1992.

[51] Cost Estimating Methodologies, Beth Dunn, Defence Acquisition University, Business, Cost Estimating & Financial Management Department, October 2002.

[52] FAA Life Cycle Cost Estimating Handbook, Investment Cost Analysis Branch, ASD-410, June 3, 2002, Chapter 10.

[53] www.aces.de

[54] www.galorath.com

[55] www.pricesystems.com

[56] Parametric Estimating Handbook Third Edition (2004), International Society of Parametric Analysts, available for download from the web site www.ispa-cost.org

[57] Stewart, R.D., Wyskida, R.M. and Johannes, J.D. (1995), 'Cost Estimator's Reference Manual – Second Edition', Chapter 7, John Wiley & Sons Ltd.

[58] FAA Life Cycle Cost Estimating Handbook, Investment Cost Analysis Branch, ASD-410, June 3, 2002, Chapter 9.

[59] www.bayesian.org

[60] PV/11/081 (2003), Bayesian techniques as used in the FACET Models, HVR Consulting Services Ltd.

[61] FAA Life Cycle Cost Estimating Handbook, Investment Cost Analysis Branch, ASD-410, June 3, 2002, Chapter 11.

[62] Cost Estimating Methodologies, Beth Dunn, Defence Acquisition University, Business, Cost Estimating & Financial Management Department, October 2002.

[63] www.is.njit.edu/pubs/delphibook/

[64] FAA Life Cycle Cost Estimating Handbook, Investment Cost Analysis Branch, ASD-410, June 3, 2002, Chapter 3.

[65] The Delphi Method: Techniques and Applications, Harold, A. Linstone and Murray Turoff, Editors, 2002.

[66] www.booksites.net/download/coyle/student_files/AHP_Technique.pdf

[67] Saaty, T.L. (1980), The Analytic Hierarchy Process, McGraw Hill International.

4.3 SUMMARY OF FINDINGS

This section describes a summary of the methods that are being used by the participating nations, based on the analysis of the matrices, introduced in Chapter 1, that were completed by the participants. Figure 4.4 shows the results of this analysis graphically.

Method		Mission need	Pre-feasibility	Feasibility	Project Definition	Design & Developm.	Production	In-service	Disengage-ment
Optimisation	Optimization				○	○	○	○	○
Simulation	System Dynamics	○	○					○	○
	Discrete Event			○	○	◒	◒	○	○
Calculation / Estimation	Analogy	●	●	●	●	●	◒	◒	◒
	Parametric	●	●	●	●	●	●	◒	◒
	Bayesian		○						
	Engineering	○	○	◒	●	●	●	◒	◒
	Catalogue								
	Rule of Thumb	○	○	○	○	◒	○		○
	Expert opinion	●	◒	◒	◒	◒	◒	○	○
Decision Support	AHP	◒	○						
	MCDA					○			

Legend		
	blank	*No nation*
	○	*1 nation*
	◒	*2-3 nations*
	●	*>3 nations*

Figure 4-4: Summary of Methods Used by the Nations.

The findings at Figure 4-4 clearly show that to generate a cost estimate all participating nations use many methods across each of the phases considered.

Looking at the categories of methods distinguished in this chapter, the calculation/estimation category is used in all phases. The analogy and parametric method are predominant and are used in (almost) every particular phase.

The engineering or bottom-up method is most popular in the phases (project definition, design and development and production) when major alternatives are compared and more detailed information is available.

In the very early phases decision support methods and system dynamics are becoming more popular. This is not surprising as these techniques can be employed using subjective judgement thus overcoming the lack of quantitative historical data.

In the design and development phase, the production phase and the in-service phase, simulation and optimisation methods are sometimes used to estimate support costs and the effects of alternative support scenarios. Not shown in the figure, but during the in-service phase activity based costing is widely used to capture actual costs.

4.4 RECOMMENDATIONS

Many cost estimates require the use of a variety of methods. It is often not possible to use a single method to estimate all the cost elements to be considered. Therefore the total life cycle cost estimate of a system will include the use and outputs from a combination of methods.

As shown in Figure 4-4 the participating nations use many different methods in each phase. It is therefore not possible to recommend a single method to estimate the life cycle costs for each phase of the life cycle.

The best cost estimating method is one that makes the best use of the data available. It is therefore recommended to employ a method that will provide as much detail as the availability of the input data will allow. Therefore, the availability of data is a major factor in the estimator's choice of estimating method.

It is also recommend that a second method is used in order to improve the confidence and to validate the life cycle cost estimate. In many cases, expert opinion or a simple rule of thumb can provide a good second estimate.

For multi-national programmes it is important that the method chosen can be used by all the nations involved, given the data available in each nation. This will probably result in a method being chosen that does not demand detailed design information and supporting data.

It is recommended that research be conducted continuously to enhance methods and models for life cycle costing.

Periodically, the US Department of Defence undertake an initiative to review the basis and techniques employed in cost estimating. This is supported by a number of academic groups and learned societies. However, these initiatives purely examine techniques that will be employed within the US. It would be beneficial to conduct a similar continual review across NATO and PfP nations.

4.4.1 References

[68] www.ams.mod.uk

[69] www.communities.gov.uk/index.asp/id=1%5b4225%5d

[70] Keeney, R.L. and Raiffa, H. (1976), Decisions with Multiple Objectives: Performances and Value Trade-Offs, Wiley, New York.

[71] Olson, D. (1995), Decision Aids for Selection Problems, Springer Verlag, New York.

[72] Yoon, K.P. and Hwang, C.-L. (1995), Multi-Attribute Decision Making, Sage, Beverley Hills.

Chapter 5 – MODELS

5.1 GENERAL

This chapter presents the results of the matrix survey, mentioned in Chapter 1, on models. The focus here is to summarise the use of models by the nations (both commercially available and in-house) and present the results in a general overview. The models used and any requirements on the use of a specific model across all of the PAPS phases will be presented. Annex A contains all the participating nations' completed matrices.

In everyday cost analysis language, the terms models and tools are often used interchangeably. This is, for instance, exemplified in the questions put forward in the matrix that the nations in the Task Group where requested to answer. It might be of interest for some other types of studies to make a distinction between the two, but for the scope of this work it has been decided that no such distinction is needed. In the Programme of Work for the SAS-054 Task Group the term (cost) model is defined as:

> *"A Cost Model: is a set of mathematical and/or statistical relationships arranged in a systematic sequence to formulate a cost methodology in which outputs, namely cost estimates, are derived from inputs. These inputs comprise a series of equations, ground rules, assumptions, relationships, constants, and variables, which describe and define the situation or condition being studied. Cost models can vary from a simple one- formula model to an extremely complex model that involves hundreds or even thousands of calculations. A cost model is therefore an abstraction of reality, which can be the whole or part of a life cycle cost."*

Using this definition, both a graphic description of the relationships that represent the abstraction or simplification of reality as well as a series of connected, specially developed computer programmes, can be a model.[1] The bulk of the models discussed in this chapter are of the latter kind, but range from very complex types of models to simple spreadsheet models. For the purpose of consistency the term model is therefore used throughout the chapter.

5.2 OVERVIEW OF MODELS

This section is a comparison on the different models that are currently in use by the nations taking part in the study. The first conclusion that can be drawn from the matrices is that no specific model for a certain phase is mandatory for any nation. Many nations do, on the other hand, have some recommendation on what type of model that should be used.

5.2.1 The Different Types of Models Identified

To begin with, among the models used by the nations, four different types of models have been categorised. These are: models for optimisation, simulation, estimation and for decision support. Each is briefly described below.

5.2.1.1 Estimation Models

This represents a broad spectrum of models that are used at the core of the life cycle costing process. As shown later in the chapter, the estimation type of model is often used, in all the PAPS phases.

[1] In some occasions it might be helpful to define a so called LCC model framework including the use of several models operating together to complete the LCC framework (see Sub-section 2.7.6).

Estimation models are all types of models dealing directly with the estimation and calculation of cost. The estimation of cost can, in turn, be supported by some other type of method, but in the case of the estimation model the main objective is to come to some sort of conclusion as to the level of cost for a system or sub-system.

Since this is a wide model category there are many examples of the estimation type models being used, both in terms of commercially available and those developed in-house. One common feature often found is that all the models employ a defined cost breakdown structure. These models are often tailored to a specific programme and, for those developed in-house are often implemented in a spreadsheet environment.

5.2.1.2 Decision Support Models

In this category, many types of operational research models with the purpose of choosing or ranking between different alternatives can be found. The models are typically based on soft management science approaches such as analytical hierarchical process or on multi-criteria decision analysis techniques.

5.2.1.3 Simulation Models

This category contains all the models based on one of the simulation methodologies outlined in Chapter 4. This therefore includes models using system dynamics and discrete event simulation. In addition, models using Monte Carlo simulation have also been included.

5.2.1.4 Optimisation Models

This category contains all the models that are based on some type of optimisation method, be it mathematical programming, heuristics, or other types of optimisation approaches. These models are most frequently used as support methods for the life cycle cost estimation process. For example, they are frequently employed to determine stock levels, maintenance regimes and supply chain impacts.

5.2.2 The Models Used by the Nations – General Overview

A first look at the different types of models shows that all nations use some form of in-house developed model for LCC analysis. The majority also use some type of commercial model. However, some nations do not use any type of commercial model; instead they rely entirely on in-house developed models and/or other types of methods such as expert analysis.

Many different types of models are used by the nations. There are for instance hundreds of models, the bulk of which are in house developed, but for this study, nearly 40 different models have been identified in the matrices. Nearly half of them are commercially available models and the other half have been developed in-house. There are differences between the in-house developed models, but one common feature is that many are developed in a spreadsheet environment and often tailored for each specific programme or project. The in-house developed models are, generally, only used by the nation that has developed the model.

Of the four categories of models identified the most prominent is that of estimation. This statement is still valid in considering the use of commercial or in-house models.

Based on the sample size of 40 models, Figure 5-1 shows the number of nations that are using a certain type of model in each PAPS phase. It also gives an indication of which types of models that are used most frequently among the nations. Note that the matrix indicates the number of nations and not the number of models.

Models		Mission need	Pre-feasibility	Feasibility	Project Definition	Design & Developm.	Production	In-service	Disengage-ment
Optimization	In-house		○						
	Commercial				○	◒	◒	◒	◒
Simulation	In-house			○	◒	◒	◒	◒	◒
	Commercial	○		○	○	○	◒	◒	◒
Calculation / Estimating	In-house	●	●	●	●	●	●	●	●
	Commercial	◒	●	●	●	●	●	◒	◒
Decision Support	In-house	◒	○						
	Commercial	◒							○

Legend		
	blank	*No nation*
	○	*1 nation*
	◒	*2-3 nations*
	●	*>3 nations*

Figure 5-1: Analysis of Nations' Matrices.

For life cycle cost analysis all the nations have in-house models that are based on a defined CBS (cost breakdown structure). Data for these models can be estimated by empiric methods and or by parametric formulae (sometimes both methods are used for completeness). For more complex cost relationships some nations use other model outputs as an input to the overall CBS model. One example of this is to use a model for optimisation of spares to calculate the cost of stock inventory (both in terms of initial investment and annual cost of spares). This provides a cost-effective support cost baseline.

During the early PAPS phases most of the cost models are used to support operational analysis studies therefore implying the need for high-level analysis and the use of in-house developed models is common.

In the later PAPS phases most models are used to support investment appraisal, logistic modelling and through life management planning. The quantity and range of applications of the models are greater from the project definition phase than for the earlier phases, this is valid both for in-house developed and commercial models.

Only a few nations use optimisation or simulation models. These are mainly used from the project definition phase and onward for optimisation of logistics resources and simulation of the support system. Optimisation and simulation methods are used to analyse system availability and endurance to support operational and tactical planning of technical system in a cost-effective way.

5.2.3 Models Used in Each Phase

This sub-section summarises on what types of models are being used in each PAPS phase by the nations. There is a strong similarity between the phases, but for the purpose of completeness each PAPS phase is described below.

5.2.3.1 Mission Need Evaluation Phase

In this phase most of the nations use models for estimation. Only a few nations have stated that other types of models are used. The most frequently used of the other type of model are those for decision support. There are only three nations that state the use of commercially available models for estimation, whereas the in-house developed models are used in greater numbers among many more nations.

One reason that nations mainly use in-house developed models in this phase could be that the level of detail and availability of data is poor in this phase. This forces the cost estimator to resolve to construct their own model. The analyses made in this early phase are often not made by experienced cost estimators and the reason for this is since the estimates by default are very rough, the perceived benefit of the experienced estimators might be negative. **However, it is recommended that a cost estimate is made by suitably experienced personnel**.

5.2.3.2 Pre-Feasibility Phase

The same pattern as in the previous phase can be observed. There is still a large collection of models used for estimation purposes and among those; the in-house developed ones are employed in greater numbers. This is probably even more so than is shown by the responses given by the nations, since five nations report the use of spreadsheet models. There are probably several of these spreadsheet models in use in each of these nations. There are, however, a few more commercially available ones being mentioned here and more than one nation is using them. One nation reports the use of more than one model for estimation purposes, therefore there seems to be an evolving acceptance of the commercially available models. The use of models for decision support has dropped to just one nation using an in-house model.

The strong preference for in-house developed models is probably, as already stated, a result of poor data availability. In this phase however, more experienced cost estimators are involved in the process, reflecting the growing use of commercial models.

5.2.3.3 Feasibility Phase

Again, the same pattern and trend as in the previous phase can be observed. The bulk of models used by the nations are still for estimation purposes and the bulk of these are in-house developed ones. In the use of commercially available models there seems to be a preference for parametric estimating models. The reported use of models has ended.

The reasons for the continued trend for in-house developed estimation models are believed to be the same as in the previous phase.

5.2.3.4 Project Definition Phase

The overall picture is the same in this phase with the bulk of models used for estimation purposes. In this phase more nations use a couple of more commercially available models. And more nations use a few different models for their estimation purposes. Of the models that the nations have reported roughly a third are commercially available ones. This is a slight misrepresentation of the fact that, as mentioned before, in the nations that report the use of spreadsheet modelling, this most probably means that more than one model is in use within each nation. Of the commercially available models for estimation, models dealing with parametric estimation seem to be preferred.

A slight trend for a growing use of models for optimisation and simulation can be seen in this phase. These models are most probably used in support for estimation models and the growing use is most likely a consequence of more data being available.

5.2.3.5 Design and Development Phase

As was mentioned under Section 5.2 the overall picture is the same in all the phases, with a strong preference in all nations for models doing estimation. In this phase, the trend mentioned for the project definition phase, with a wider spread use of models for optimisation or simulation is still in place. These optimisation models are either used to optimise stocks of spares and use this as input in the

calculation of a larger investment programme, or they are used to estimate cost of optimised inventory of spares.

The fact that a growing portion of all models reported are commercial indicates a growing reliance on commercial models and this might be due to the fact that data is more readily available at this and the following stages.

5.2.3.6 Production Phase

As before, models for estimation are still the ones being used the most among the nations, but the trend towards a more widespread use of optimisation models or simulation models or a combination of them, continues, and is even slightly emphasised – though it can hardly be said to be widespread. There are almost as many commercial models as in-house models reported in this phase. Again, this appearance might be false, since the use of Excel-based models might indicate that more than one such model is used in each of the nations that have reported their use.

5.2.3.7 In-Service Phase

The picture is almost identical as in the production phase, but only three nations are still using commercial ones. As in the three previous phases, a growing number of nations are using optimisation models or simulation models. The distribution between the use of in-house developed models for estimation and commercial ones is about the same as in the production phase.

5.2.3.8 Disengagement Phase

Regarding models for estimation, there is a slight drop in numbers in both in-house and commercial models, but the number of nations employing them is the same. The number of models used for simulation is the same as in the four previous phases, but only one nation still uses a specific model (commercial) for optimisation. In this phase, one other nation again reports the use of a decision support model.

5.3 RECOMMENDATIONS

From the material, it is clear that what has here been labelled models for estimation are the preferred models for life cycle cost analysis. There is also a clear pattern that to supplement models for estimation, more models for decision support are used in the earliest phases and more models for optimisation and simulation are used later on.

To ensure Best Practice, the use of more than one model is recommended. For the purpose of verifying results, more than one method of estimation should be used and this means that if data permits, two or more models for estimation can be used. If data is available, the use of models for simulation and/or optimisation to supplement models for estimation is recommended. The use of multiple models should always be evaluated on from a cost-benefit point of view. In the earliest phases, scarcity of data often means that the recommended model to use is a decision support model.

When it comes to multi-national programmes, there is a need for all participating nations to understand and trust the models used. The participating nations will need to agree on at least one common model or framework (see Sub-section 2.7.6). There is also a need to be clear on which data to use and how to collect this data. One way of handling these needs is to use one or more commercial models, maybe supplemented with national models, for multi-national programmes.

There is no single model, of all the models presented by the nations that cover all aspects, so in Section 5.4 there will be a description of some of the more prominent attributes a good model should have.

These attributes can also be used as a checklist when creating or constructing an in-house model or when evaluating a commercially available model.

5.4 DESIRED MODEL ATTRIBUTES

The characteristics[2] of a high quality cost estimates are:

- Accuracy;
- Comprehensiveness;
- Ability to Replicate and Audit;
- Traceability;
- Credibility; and
- Timeliness.

Each of the above should demonstrate these quality characteristics in the following ways:

- **Accuracy** – Cost estimating relationships (CERs) will be the result of regression analysis with good curve fits and minimal error bands, making them valid predictors of cost. Estimates should be unbiased, not 'low balled' or overly conservative, but based on an assessment of the most likely costs. Underlying data will have been correctly normalised for technical baseline and for inflation using appropriate guidance. The time phasing of the estimate should also be logical and accurate.
- **Comprehensiveness** – Estimates should use a cost breakdown structure that is at a level of detail appropriate to ensure that cost elements are neither, omitted or double-counted. All the cost driving ground rules and assumptions must be detailed in the documentation of the cost estimate.
- **Replicability and Auditability** – The estimate should be presented in a cost breakdown structure and work breakdown structure that is fully traceable to the system specification. The estimate documentation should include source data, significance and goodness of fit statistics for CERs, clearly detailed calculations and results and explanations for why a particular method or reference was chosen. An independent reviewer must be able to follow the estimating process, repeat the calculations and arrive at the same answer.
- **Traceability** – Data should be traceable back to the source documentation.

Without these characteristics the estimate will not be **credible**, which is the most important quality of a good estimate and the benefits just discussed will be much harder to realise. Finally, an estimate must be **timely**. The best estimate in the world does no good if it is too late to provide decision makers the insight needed.

A cost model must therefore be able to demonstrate that it meets the characteristics listed above and is fully documented in order to justify the life cycle cost estimate produced.

[2] These characteristics are given in the Society of Cost Estimating and Analysis training programme – CostProf © – Programmed Review of Fundamentals. They are replicated here by kind permission of the SCEA Office.

5.5 COST MODEL VALIDATION – A PRACTICAL PROCEDURE

5.5.1 Preamble

The following sub-sections set out a practical procedure for validation[3] which can be carried out irrespective of the amount of detailed data on specific projects available. However, the confidence which can be placed on the validation is obviously dependent on the number of projects for which outturn costs can be provided and the reliability of those outturn costs.

5.5.2 The Procedure

The procedure described here would be applicable to the form of model comprising only cost estimating relationships derived by statistical analysis of the costs of the past projects and relating costs to objective quantitative design and/or performance characteristics of the product. It can be used also for methods involving non-physical ‘complexity factors’ or equivalents providing that those factors are all derived via relationships linking to objective quantitative design and/or performance characteristics in unambiguous and repeatable fashion. In that case, those relationships must be declared prior to any trials and adhered to without change throughout such trials. However, it is important to note that there is a numerically important class of model that relies upon the subjective judgement of the user to set values for ‘complexity factors’ or equivalents. For such models, validation is neither possible by the means described here nor by any other method.

5.5.3 Review of Basic Data

Obtain a list of projects upon whose costs the model being validated is based, including names of projects.

The important thing at this stage is to establish that the projects on which the model is based all belong to a well defined class or generic type. A list is sufficient for this purpose.

5.5.4 Test Regression

Predicted costs are then used as the explanatory variable in a test regression to derive: actual cost = f(predicted cost). The test statistics (n: number of observations, r: correlation coefficient , σ: standard error) of such a regression provide a summary of the performance of the model.

5.5.5 Calibration Tests

The model is tested against data not used in its construction, using **outturn** values of design and performance characteristics as input.

5.5.6 Prediction Tests

A more rigorous test than calibration is the prediction test. In this test, outturn cost data not used in the construction of the model is compared to the estimates made by the model based on contemporary accounts of the performance and/or other characteristics required of the project at an earlier stage of its evolution (typically when development of the project in question was commenced).

As with calibration tests, the mean and population standard deviation of the cost estimating errors are calculated. It is to be expected that errors incurred during use in the prediction mode using performance

[3] Reference is made here to the procedure for validating cost estimating models used in cost forecasting. The full statistical and practical procedure reference PV/11/098 is available from HVR Consulting Services Ltd.

requirements will be larger than in the calibration mode when working from details of the design of the equipment in question. However, it may be difficult to find sufficient data to carry out an adequate prediction test since people constructing cost models tend to base their models on all the projects on which they have outturn data. They are naturally reluctant to set data aside for use in prediction tests when they could be incorporated in the model to its benefit.

5.5.7 Mixed Tests

In some cases, the actual projects on which the model is based may not be known and in this case the person carrying out the validation must depend on his own database. In this situation, he simply compares the outturn costs of as many projects as possible of the specified type with the costs estimated using the model and calculates the mean and population standard deviation of the estimating error. It is important, however, that the database used by the person carrying out the validation is agreed prior to the trial.

5.5.8 Frequency/Probability Distributions

For some models, there may be sufficient data to make possible the construction of graphs showing the probability of forecasting errors exceeding a given percentage of the actual outturn along the lines of Figure 5-2 (or as histograms of the frequency with which forecasting errors occur). Such graphs are exceedingly useful, in that they reveal both the accuracy of estimates and any bias.

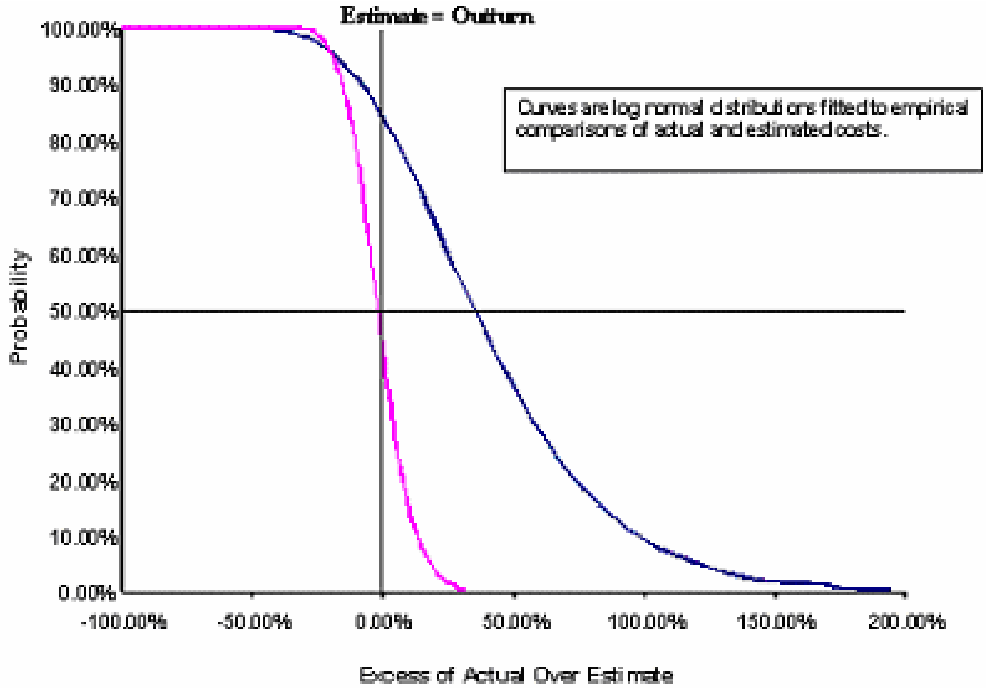

Figure 5-2: Comparison of Two Models.

However, a very large data set is required for meaningful results to be obtained.

5.5.9 Judging the Comparative Validity of Models

The procedure described above can enable those responsible for validating models, first to establish qualitatively that each model covers a well defined class of equipment and then calculate a number of measures of its comparative validity. The word ‘comparative’ needs to be emphasised. The procedure is

best used to judge whether one model is more likely than another to be useful, having regard to the fact that its application to future projects will invariably involve some extrapolation beyond the data set on which it was based. However, it is necessary to take complete account of the prediction errors set out in the statistical methods upon which the cost model is based.

Chapter 6 – DATA COLLECTION

In terms of time, effort, and resources consumed, collection of data is a major part of a life cycle cost study. Life cycle costing is a data driven process, as the amount, quality and other characteristics of the available data often define what methods and models can be applied, what analyses can be performed, and hence, the results that can be achieved.

It is important to bear in mind that, because the quality and value of life cycle cost and life cycle management analyses is highly dependent on the quality of the available data, good data represent real value for a materiel programme. Conversely, real costs are associated with the collection and storage of data.

This chapter will take the broad view and define data as any type of information used in a life cycle cost analysis.

Data collection for risk analysis is a topic that requires extra attention, and is therefore covered separately in Sub-section 7.4.

6.1 EVOLUTION THROUGH THE LIFE CYCLE

As a system progresses through the life cycle, the types of data available evolve in a number of ways. As this in turn defines the task of data collection and the life cycle costing process in general, it is important to be conscious of these developments.

First and foremost, the amount of data available increases as the system becomes better defined. Obviously, very little is known about the end system when a project begins and all that exists is an identified capability gap or a general concept, whereas, when a system is in service, the system and its environment can be documented in almost infinite detail. Unfortunately, because uncertainty, risks, and opportunities decrease as the life cycle progresses, the need for knowledge is the greatest at the earliest stages. This means that more time and resources should be allocated to the data collection effort at the earlier stages of the life cycle.

The characteristics of the available data will change as well as the progress of the life cycle. Early data will tend to be softer and be in a more aggregated form, because hard numbers and detailed information are not yet available. For example, an early concept may stipulate a high engine reliability, which is later quantified as an expected or required mean time between failures for the engine itself and later still for the various parts of the engine.

Chapter 3 gave an overview of the relevant data sources for each phase of the life cycle of a system. ***It is recommended to anticipate future data requirements and to collect data accordingly.***

6.2 DATA SOURCES

Life cycle costing requires a wide variety of data, and these must be collected from an even wider variety of sources. A distinction can be made between primary data, coming directly from the source, and therefore generally of better quality and utility, and secondary data, which is derived, possibly altered in the process, and therefore of inferior value.

When preparing a cost estimate, estimators should consider all credible data sources. However, primary sources of data should be given the highest priority for use whenever feasible.

Table 6-1 illustrates the difference between primary and secondary data, using the following definitions of primary and secondary sources of data for classification purposes:

- Primary data are obtained from the original source. Primary data are considered the best in quality, and ultimately the most reliable.
- Secondary data are derived (possibly sanitised) from primary data, and are therefore, not obtained directly from the source. Because secondary data are derived (actually changed) from the original data, it may be of lower overall quality and usefulness.

Table 6-1: Sources of Data

Sources of Data	
Typical Data Sources	**Source Type**
Basic Accounting Records	Primary
Cost Reports	Either (Primary or Secondary)
Historical Databases	Either
Functional Specialist	Either
Technical Databases	Either
Other Information Systems	Either
Contracts	Either
Cost Proposals	Either

As already indicated, in the early stages the system itself is non-existent, so data will have to come from comparable systems and programmes. This means that data will primarily come from outside the programme, whereas in the later stages, more data will be generated internally by the project itself. This makes data sources for the earlier phases harder to identify and access and it makes data collection and validation more difficult.

Outside data sources can be industry or other branches of the military or the government. They can be domestic or from other nations. It is worth noting the existence of the NATO agreement on the communication of technical information for defence purposes (Reference: [67]), which covers the communication of proprietary technical information among the signatory NATO nations and NATO bodies.

In these early stages, a certain creativity and flexibility will often be necessary, because most data will have to come from outside the programme. This means that comparable systems and programmes, as well as the relevant data sources within these, must be identified. Data from comparable systems must then be modified based on differences between systems with respect to performance, complexity, maturity of technology, etc. (see Sub-section 6.5 on data normalisation). This task is highly dependent on the specifics of the individual programme, and no generalised or automated methods can be applied. Furthermore, care must be taken to ensure that reference systems are in fact comparable to the system of interest. Use of radically different technology, differences in operating profile, etc., for a new system may mean that data from older systems are irrelevant.

Ideally, it should be proven statistically that a credible relationship exits between the relevant data for a reference system and the system of interest. This, however, is rarely feasible in practice, but ***since the use of assumed or uncertain relationships should be reflected in the uncertainty of the final estimate, it is recommended that evaluation, statistical or otherwise, of the certainty of such relationships are performed.***

At the earliest phases, expert judgment or opinion may be the only available source of information, and it represents the extreme aggregate and soft end of the spectrum. Expert judgment can be viewed as data or as a source of data, but in essence it is a black box analysis of more or less well documented data and experiences. Since it is largely impossible to validate, it is useful if at all possible to get more than one opinion.

Again, these tendencies point to a more manual, creative, labour intensive effort in the early stages of the life cycle.

From the production phase onwards, hard data from tests and in service use, generated within the programme itself, begin to become available. Such data are increasingly collected in ERP (Enterprise Resource Planning) systems and other database systems such as the VAMOSC (Visibility And Management of Operation and Support Costs) databases maintained by various branches of the US military. This in turn allows more automated collection of data in reports and tables for use in the further study of the system itself or of comparable systems at an earlier stage in their life cycle. However, because the need for and availability of various types of data changes throughout the life cycle, data collection is and remains in essence a manual task.

Some data sources, such as contractors and sources external to the defence organisation, will change often, maybe with each new life cycle cost programme, while others, such as maintenance and accounting functions within the defence organisation, will be used repeatedly by the life cycle cost function. It is immensely helpful if there is an understanding of life cycle cost by these repeat providers of data, including how and why it is done and how it is used. This will help ensure that the cost analyst is given the right data of the best quality. Conversely, if there is a widespread feeling that data collection is a pointless chore that generates no value, data quality will drop. This will in turn generate poor estimates, perpetuating a vicious cycle by lending further credence to negative feelings about life cycle costing. Hence, time and effort spent on selling life cycle costing within the defence organisation, informing data providers on how their output is used, may prove very well spent.

It is important in this context to note the value of storing data from past projects and programmes for future use. Though it is important to remember the costs associated with storing data, this just underlines the benefits of anticipating future data needs, and to store the right data in an appropriate format.

6.3 DATA DOCUMENTATION, FORMATS AND STANDARDS

Electronic exchange of data between ERP systems and databases can be a cumbersome and time consuming affair if data formats and data models differ. However, a number of standards exist for the exchange of life cycle data. For some years, the official NATO standard has been the NPDM (NATO Product Data Model), formerly known as NCDM (NATO CALS Data Model). An international standard exists in the form of ISO 10303-239 (STEP, Application protocol 239 – Product Life Cycle Support, PLCS), which has been put forward by NATO to be adopted as STANAG 4661[1].

PLCS provides an application specific but generic and flexible data model for life cycle data. Industry and organisations can tailor this for their specific application using RDL (Reference Data Libraries). Needless to say, this generic data model for all life cycle data is extremely large and complex. This problem is dealt with by defining DEX (Data EXchange Sets), which are subsets of the data model suited for a particular business process, such as the DEX D005 on Maintenance Plan.

Future development of PLCS, including the definition of new DEX, is overseen by a technical committee under the OASIS (Organisation for the Advancement of Structured Information Standards) consortium.

[1] PFP(AC_327)D(2006)0002 (Draft Edition 1), STANAG 4661 on Product Life Cycle Support.

The Cooperation on Defence Implementations of PLCS (CDIP) has been formed to undertake defence related aspects of this work.

As indicated, the PLCS is a very large and technically complex mechanism, and implementing PLCS would be a huge undertaking for any organisation. It is therefore not feasible, for instance, to require industry or other partners to adopt PLCS as a pre-condition for collaboration. In such cases, other, simpler, standards must be found (The OASIS homepage is a good source). Alternatively, ad hoc solutions in the form of agreed upon and documented templates, etc., may be used, but this makes the data harder to use at a later date for other projects or purposes. When possible, officially defined and accepted standards should be preferred.

In the long term, as it has been adopted as an ISO standard and by NATO as a STANAG, and with continued support and development by industry and nations, PLCS has potential to be an important tool to help collect and exchange high quality, well documented data.

6.4 DATA FROM SUPPLIERS/CONTRACTORS

Various mechanisms can be employed to gather data from contractors. The use of a life cycle cost questionnaire is particularly recommended and examples of such questionnaires are provided at Annex C.

Though today data can be shared easier than ever before, it takes time and resources to measure, collect, and manage data. Therefore, it must be understood that data comes at a price, and that it is entirely reasonable for contractors, suppliers, and others to charge a price for data, even if this is part of a major weapons system purchase. The upside of this is that it is then possible and reasonable to make demands on the validity and accuracy of the data received.

In this context, it is particularly important to anticipate future data requirements and to frame agreements and contracts accordingly. The timing of collection and delivery of the data as well as the contents and formats of the required data should be clearly defined. The quality and reliability of data from suppliers is often inferior. Whether this is caused by a lack of incentive or ability, ***it is recommended to have previously agreed upon and well documented templates or standards for the data to be exchanged***.

However, a contractor will often have an interest in presenting a system in the best possible light. Care must therefore be taken to secure that the data received from contractors, or other sources with a vested interest in a programme, are accurate and unbiased. This can take the form of a contract or other binding agreement which puts some form of penalty, possibly some or all of the costs and risks arising from errors and omissions, on the contractor.

The UK MDAL (Master Data and Assumptions List) (see also Sub-section 2.3.2.1; see also Reference [73]) is one well documented mechanism for ensuring that all stakeholders buy into a common and clearly stated understanding of the project and the system of interest. A document like the MDAL needs to be dynamic and iterative, but it also needs to be frozen at certain points (milestones) in the life cycle to provide documentation of decisions taken at this point and support audit of these decisions. This process is illustrated in Figure 6-1.

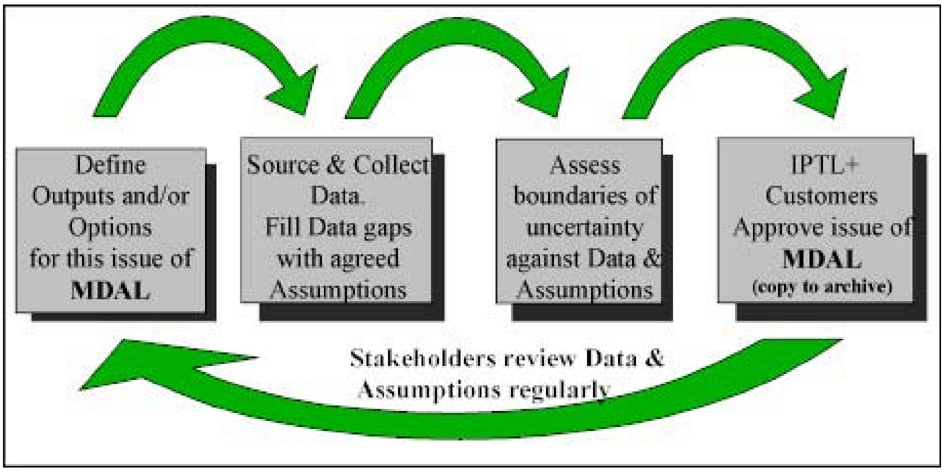

Figure 6-1: Development of Master Data and Assumptions List[2].

A similar function is fulfilled for major acquisitions of the US DoD by the CARD (Cost Analysis Requirements Description) (further details are provided at Section 2.3.2.2). The CARD is used to formally describe an acquisition programme, including the system itself, for the purpose of preparing all cost estimates for the programme. It is provided at major milestone decision points for materiel programmes and for major information system programmes whenever an economic analysis is required.

Furthermore, the US DoD has developed the CCDR (Contractor Cost Data Reporting) system for accumulating actual contractor costs necessary to analyse costs efficiently and effectively. The CCDR contains forms and templates for reporting required cost data and provides extensive guidance on mandatory and recommended policies and processes to be followed by contractors for major materiel systems. The main components of the CCDR system are:

- The **cost and software** data reporting plan. This form, referred to as the CSDR plan, specifies the WBS[3] (work breakdown structure) elements, the specific report format and the reporting frequency.
- The **cost data summary report**. This form captures all contract WBS elements at the level specified in the CSDR plan and includes both recurring and nonrecurring breakouts.
- **Functional cost-hour and progress curve report**. Part I of this form, functional cost-hour report, is directed at selected WBS elements where more detailed cost data are needed. It contains a functional breakout (e.g. engineering and manufacturing) and a cost element breakout (e.g. direct labour and material) within functional categories. Part II, progress curve report, captures recurring costs on lot or unit data for selected WBS elements.

A similar mechanism exists for information systems and other software heavy acquisitions in the form of the SRDR (software resources data report). The CCDR and the SRDR are each described in a separate manual which are available on the internet:

- DoD 5000.4M-1 Contractor Cost Data Reporting (CCDR) Manual, 4/1999 (See: Ref. 78) http://www.dtic.mil/whs/directives/corres/html/50004m1.htm
- DOD 5000.4-M-2 Software Resources Data Report (SRDR) Manual 2/2004 (See: Ref. 79) http://dcarc.pae.osd.mil/srdr/DOD50004M2.pdf

2 From www.ams.mod.uk/ams/content/docs/wlc/wlcmdal.htm

3 WBS is similar to Cost Breakdown Structure (CBS) as defined by SAS-028.

While data collection through formal reports such as CCDRs and SRDRs is extremely important and beneficial, there is still no substitute for taking the time to understand and verify the accuracy of historical information, and the programmatic context in which it was obtained.

6.5 DATA NORMALISATION

In Sub-section 6.2, the concept of primary and secondary data was introduced, and it was indicated that primary data are preferable. However, since raw data come from a variety of sources, there is generally a lack of uniformity in data and therefore a certain amount of normalisation will be unavoidable. Generally speaking, data normalisation covers changes and adaptations made to primary data to make it applicable in a given model. It is defined by SCEA (Society of Cost Estimating and Analysis) as:

- To adjust a measured parameter to a value acceptable to an instrument or technique of measurement.
- For a data base: to render constant or to adjust for known differences.
- For cost or dollars/Euros: Then-Year dollars/Euros and/or actuals are escalated to a common Base Year for comparison.

The last definition in particular will be relevant for cost data. However, normalisation can take many different forms and have different specific purposes, such as:

- Adjusting costs to a common year or adjusting to different inflation or discounting mechanisms or other variations in accounting standards.
- Adjusting system or parts costs for technical specifications like size, weight, complexity, technological maturity, etc.
- Adjusting costs or technical performance data such as failure rates for different operating profiles like operating temperature, mileage, etc.
- Adjusting prices for lot size, learning curve considerations, producer capability and maturity, etc.
- Adding cost items not originally included, for example through error or because of a different costing scope, or removing cost items which are not applicable.

Regardless of how data are normalised, exact, complete and detailed documentation of the process is very important. This is the case whether normalisation of primary data is performed as part of the life cycle cost estimating process or secondary data has been obtained for use in life cycle cost estimation. Serious errors can occur if data is not properly understood and interpreted. It is therefore vital to fully understand data and to know where data is coming from.

The next sub-sections describe the relevant issues related to cost data normalisation.

6.5.1 Base Year

The first step is to establish an appropriate base year for data normalisation. A base year is a fiscal year whose mid-point is selected as a reference point for computing an index. A programme base year is usually the year of initial programme funding. Normalising to the programme base year facilitates the analysis of data on a comparative basis during the cost estimating process.

6.5.2 Constant Years versus Current Years

An estimate is said to be in constant dollars or Euros if costs are adjusted so that they reflect the level of prices expressed in the dollars/Euros of a fixed base year. The terms real or constant are used

interchangeably to refer to the purchasing power of the dollar/Euro for the specified base year. When cost estimates are stated in real dollars/Euros, the implicit condition is that the purchasing power of the dollar/Euro will remain unchanged over the time period of the programme being costed. Normalising data due to inflation allows an estimator to track price changes explained by other causes.

Current year costs reflect the purchasing power in existence when expenditures are actually made. Prior costs expressed in current year dollars/Euros are the actual amounts paid out in those years. Future costs stated in current year dollars/Euros are projected amounts to be paid, including the changes in the purchasing power of the dollar/Euro. Terms as current, then-year and nominal dollars/Euro are sometimes used interchangeably.

Cost estimates normally are prepared in constant dollars/Euros to eliminate the distortion that would otherwise be caused by price-level changes. This requires the transformation of historical or actual cost data into constant dollars/Euros. For budgeting purposes, however, the estimate must be expressed in current year dollars/Euros to reflect the programme's projected annual costs by budget appropriation. These annual appropriations actually are expended over a number of years. This requires that the appropriation request takes into account the effect of the anticipated inflation that corresponds to the outlay pattern for each appropriation. The dilemma facing the estimator is how to bridge the gap between the estimate in constant year dollars/Euro and a budget request in current year dollars.

6.5.3 Using Indices

As mentioned before in order to compare cost incurred or estimated for different years asks for converting costs from one year to reflect the price level of another year. Price or other indices can be used to accomplish this conversion. An overview is given (see reference: [79]) on how to select the right index and how to use these indices.

6.5.4 Exchange Rates

The use of foreign exchange rates is a problem unique to analyses performed on international programmes where costs are stated in foreign currencies. This is particularly prevalent in multi-national programmes. It is usually difficult to obtain reliable forecasts of foreign exchange rates. One approach is to assume that if inflation in the foreign country is greater than own country inflation, the rise in foreign prices will be fully offset by currency devaluation (this is the concept of 'purchasing power parity').

In multi-national programmes, usually a base currency and a base year date is agreed upon, e.g. it is agreed upon that all costs will be express in constant Euros, July 1st, 2006 or economic conditions July 1st, 2006. In this case costs calculated in other currencies need to be expressed in Euros using the exchange rate for that particular date. For example, 1 US dollar = 0.83 Euro. This exchange rate would then be used throughout the study.

A typical process for using exchange rates is shown below:

- **Step 1.** If the foreign values are expressed in constant value, note the base year. If they are first expressed in current value, deflate by using the appropriate foreign compound index. The result of this step is that the costs will be expressed in constant currency for a known base year.
- **Step 2.** Multiply the result from step (1) by the own/foreign currency exchange rate for the known base year. The result of this step is the constant currency costs.
- **Step 3.** With the costs now established, multiply these costs by the proper inflation values using the base year established at step (1). These will be the costs to be included in the estimate.

6.5.5 Inflation

Inflation is a consistent rise in the costs (prices) of goods and services over time. To introduce the effect of inflation into economic analysis, the following inflation-related terms are defined:

- Constant currency (Euros, Dollars, GB Pounds, etc.). Constant year currency values are the result of having the effects of inflation removed. Constant year currency values are always associated with a base year; for example, fiscal year (FY) 1995.
- An estimate is in constant currency if the costs for all the work is adjusted so that they reflect the base year level of prices. When prior or future costs are in constant currency, the figures given are adjusted to presume that the "buying power" of the currency was the same and will continue to remain the same as in the base year. The use of constant currency assists in the evaluation of resource requirements over time because it removes distortions which are attributable only to price level changes. With the removal of inflation, the true cost growth of a system can be more readily determined.
- Current or then year currency. Current year values are expressed in the value of the year in which a cost is expected to occur, and therefore reflect the effects of inflation. The term "current year" means that the amount is appropriate for the year in which the money is expected to be expended. When prior costs are stated in current year values, these values are the actual amounts paid out. When future costs are stated in current values, the figures given are the actual amounts which will be obligated including any amount estimated for future price change. When making estimates for the future, assume a base buying power for each currency unit (constant values) and then apply an inflation factor that converts the estimate into current year values.

6.6 REFERENCES

[73] See http://www.ispa-cost.org/PEIWeb/newbook.htm to obtain a copy of the "Parametric Estimating Handbook" from the International Society of Parametric Analysts.

[74] See http://ceh.nasa.gov/ to obtain a copy of NASA's "Cost Estimating Handbook".

[75] PFP(ACQPR)D(2003)2, NATO Agreement on the Communication of Technical Information for Defence Purposes.

[76] http://www.usmcvamosc.com

[77] http://www.navyvamosc.com

[78] ISO 10303-239 (PLCS).

[79] http://www.plcs-resources.org

[80] http://www.oasis-open.org/committees/tc_home.php?wg_abbrev=plcs

[81] http://www.ams.mod.uk/ams/content/docs/wlc/wlcmdal.htm

[82] DoD 5000.4M-1 Contractor Cost Data Reporting (CCDR) Manual.

[83] DoD 5000.4M-2 Software Resources Data Report (SRDR) Manual.

[84] http://dcarc.pae.osd.mil (US Defense Cost and Resource Center (DCARC). CCDR and SRDR manuals are found here).

[85] FAA Life Cycle Cost Estimating Handbook, Investment Cost Analysis Branch, ASD-410, June 3, 2002, Chapter 5.

[86] SCEA glossary.

[87] Cost Estimating Guide, US Department of Energy, DOE G 430.1-1, March 1997.

Chapter 7 – UNCERTAINTY AND RISK

7.1 INTRODUCTION

Life cycle cost estimates of weapon system acquisition programmes are inherently uncertain and risky. Estimates are often made when only 5% of a programme's total cost is known. Years of system development and production, and decades of operating and support costs, need to be estimated. Estimates, in turn, are based on historical samples of data that are almost always messy, of limited size, and difficult and costly to obtain. Indeed, great efforts are usually required to squeeze usable information from a limited, inconsistent set of data. And no matter what estimation tool or method is used, historical observations never perfectly fit a smooth line or surface, but instead fall above and below an estimated value. To complicate matters, the weapon system under study is often of sketchy design. Only limited programmatic information may be available on such key parameters as schedule, quantity of units to be of the system may actually change as the system proceeds through development and even production. Increases in system weight, complexity, and lines of code are commonplace.

For all of these reasons, a life cycle cost estimate, when expressed as a single number, is merely one outcome or observation in a probability distribution of costs. That is, the estimate is stochastic rather than deterministic, with uncertainty and risk determining the shape and variance of the distribution. To better support senior leadership, some sense of risk and uncertainty needs to be presented along with the point estimate. This chapter, through the following sections, demonstrates how to do this by providing guidance on the following:

- Definitions.
- General approach.
- Risk data collection.
- Estimation process.
- Cost and budget Risk.
- Sensitivity analysis.
- Appendix 1: Optimism Bias.

7.2 DEFINITIONS

The terms "risk" and "uncertainty" are often used interchangeably, but they are not the same.

- **Uncertainty** is the indefiniteness or variance of an event. It captures the phenomenon of observations, favourable or unfavourable, falling to the left and right of a mean or median value.
- **Risk** is exposure to loss. Or, in a weapon-system acquisition context, it is a measure of the potential inability to achieve overall programme objectives within defined cost, schedule, and technical constraints, and has two components: (1) the probability/likelihood of failing to achieve a particular outcome, and (2) the consequences/impacts of failing to achieve that outcome.[1]

Risk and uncertainty, then, are related. Uncertainty is probability while risk is probability and consequence, as Figure 7-1 shows. The next section of this chapter outlines a procedure for estimating risk and uncertainty.

[1] "Risk Management Guide for DoD Acquisition," Fifth Edition, June 2003; U.S. Defense Acquisition University; p. 7.

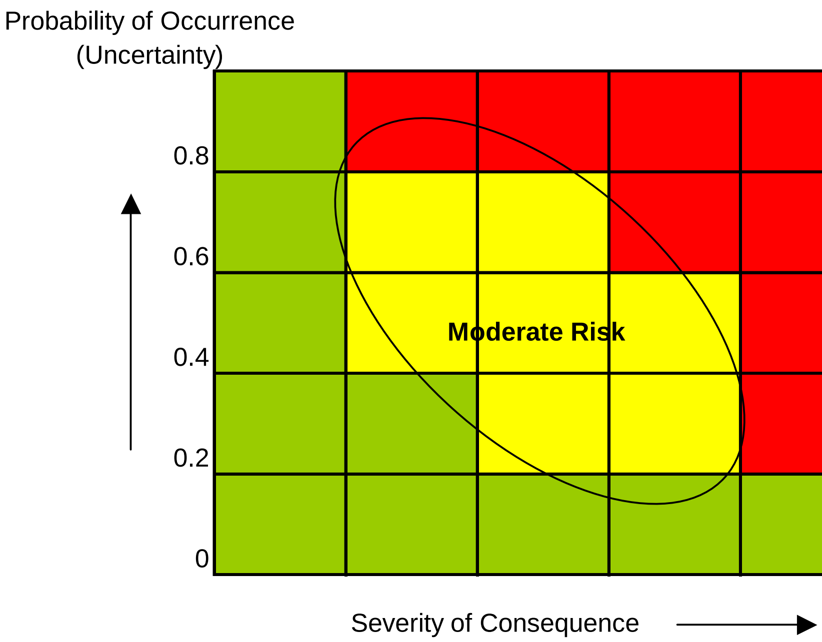

Figure 7-1: Risk Matrix.

7.3 GENERAL APPROACH

There are a wide variety of methods and models available for conducting risk and uncertainty analysis of life cycle cost estimates of weapons systems. These include simple techniques such as adding a risk factor or percentage to a bottom-line estimate (see: Appendix 1, "Optimism Bias") and sensitivity analysis. Each, if used properly, can give scientifically sound results, but first a word of caution – based on the collective experience in cost estimating within the government and in the private sector, it is fair to say that the sophistication and underlying theory of many popular models often far exceeds the quality of the basic data inputs.[2]

There is simply no substitute for taking the time and effort to understand the technical risks and challenges in developing and producing sophisticated defence systems.[3] Historical analogies must be obtained. Information from subject matter experts must be elicited. Risk and uncertainty analysis cannot be relegated to an eleventh hour exercise based on flimsy inputs.[4]

7.3.1 Overview

Figure 7-2 presents an overview of a process for estimating risk and uncertainty.[5] ***While other techniques and variations of this process are available, the paradigm shown below is highly recommended***.

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[2] Informal survey by the Naval Center for Cost Analysis in 2004 of 12 cost-estimating organizations in the United States and "Portfolio Management for New Product Development: Results of an Industry Practices Study," Drs. Cooper, Edgett, and Kleinschmidt; Product Development Institute; 2001; page 20. The "popular models" referenced by these authors are Crystal Ball and @Risk, the same two commercial models used most frequently in defense cost analysis in the United States.

[3] Biery, Hudak, and Gupta refer to this as "the most crucial … but generally overlooked" step in performing risk and uncertainty analysis. "Improving Cost Risk Analyses," 1994, p. 1.

[4] Interestingly, Dr. Cooper reports that one firm in his sample studied the historical accuracy of their probability estimates and found an average error of 300%.

[5] Much of the methodology presented herein was developed by Mr. Tim Anderson, Aerospace Corporation in collaboration with Dr. Steve Book MCR Federal Inc.

It provides outputs that have proven useful in responding to demands of senior executives for relevant information on budget risk on major acquisition programmes. More specifically, the process enables decision makers to budget a programme at a specific cumulative percentage level of risk, or, to fully understand the consequences of living within an already established budget. And it enables them to know the financial impact of specific, discrete risk events such as failure to successfully design a new fighter engine within fiscal and schedule constraints.

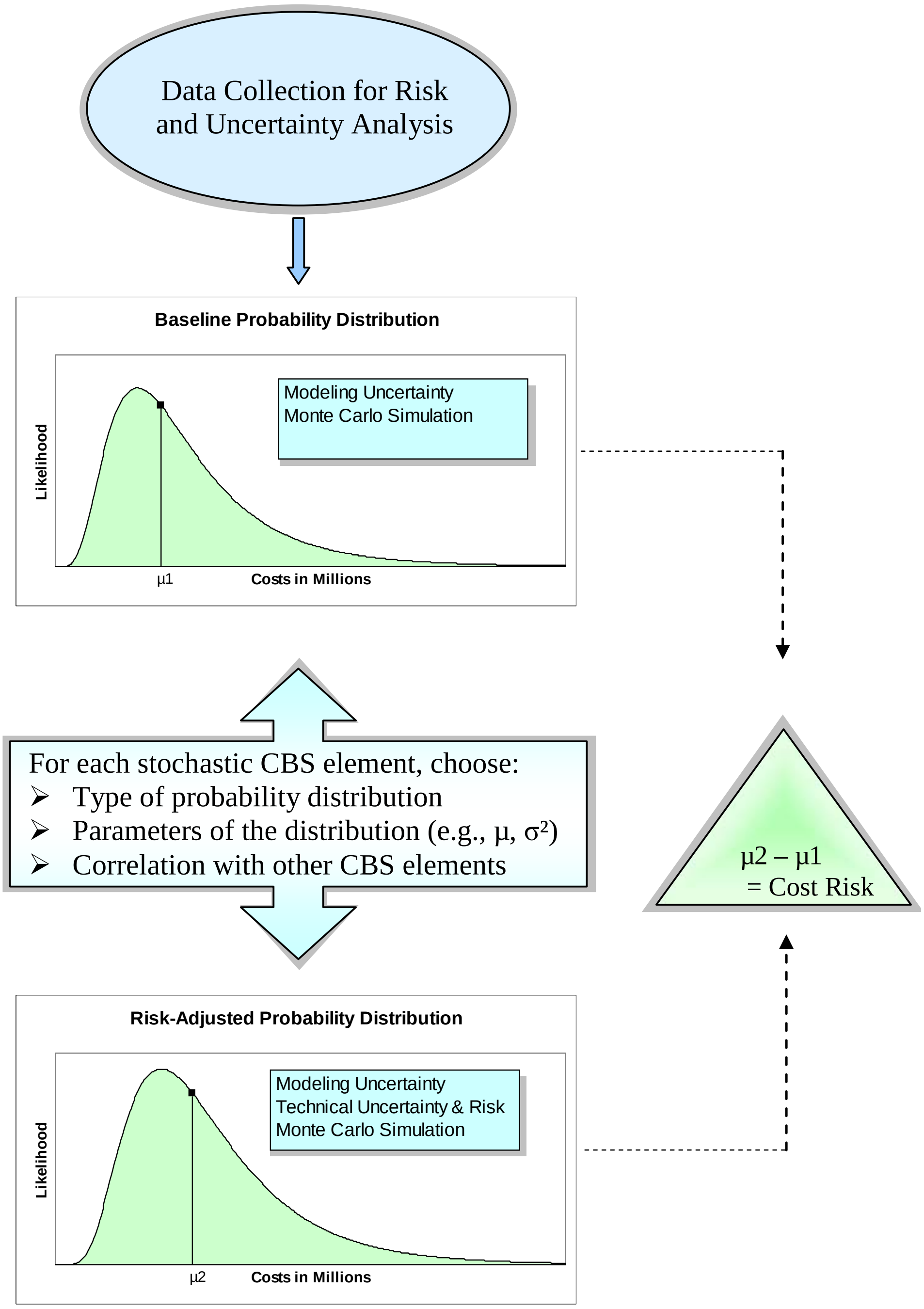

Figure 7-2: Process of Estimating Risk and Uncertainty.

The most important part of the process of estimating risk and uncertainty, and probably the most difficult, is data collection and analysis. All variables in the cost estimating model potentially affected by risk and uncertainty first need to be identified. These variables often include simple ratios and factors as well as more sophisticated CERs (cost estimating relationships) based on regression analysis. Probability distributions need to be estimated or selected for each variable. This entails first choosing the type of distribution to apply and then estimating the distribution's parameters such as high, low, and most-likely values. Popular distributions for this step include the normal, log-normal, and triangular. There are a number of techniques used to cull or estimate distribution types and parameters, such as using checklists or sound engineering judgment. Each is described in Sub-section 7.4.

It is also important in the analysis phase to identify discrete risk events, or unfavourable outcomes that might occur in developing, manufacturing, and operating weapons systems. An example might be failure of a new, state-of-the-art radar to work as intended when integrated on a ship or aircraft. For each of these risk events, probability distributions also need to be estimated or selected as well.

After the data collection and analysis phase, the analyst first generates a baseline cost estimate using Monte Carlo simulation followed by a risk-adjusted cost estimate. The output of each estimate is actually a frequency distribution of total costs, or, more technically, a probability density function, rather than a single number. It is essential to convey to senior leadership the notion that cost estimates are uncertain, that programmes can and do incur difficulties, and that the probability of a cost estimate becoming reality, when expressed as a single number, is actually zero.

In generating the baseline cost estimate, the analyst first regards as fixed the values of the explanatory or independent variables (Xs) in each of the cost model's CERs. Values of the Xs are usually found in the programme's CARD (Cost Analysis Requirements Description), or in the APB (Acquisition Programme Baseline). The baseline estimate does capture uncertainty in the relationship between dependent and independent variables in each CER. This uncertainty, in turn, results from three possible, though not mutually exclusive, sources:

- **Limited data.** In explaining changes in the cost of any CBS element, the list of relevant factors may be extended ad infinitum. However, due to data availability, perhaps only two or three of these factors are included in the analysis. Indeed, sometimes it is lucky to get just one relevant explanatory variable. The CER, then, becomes an over simplification of the complexities of reality. Errors result.
- **Human unpredictability.** Over and above the total effect of all relevant factors, there is a basic and unpredictable element or randomness in human responses that can be adequately characterised only by the inclusion of uncertainty in the analysis. This will hold as long as people rather than machines acquire and build weapons systems.
- **Errors of observation or measurement.** Cost and technical data are almost always difficult to obtain and are often of less than perfect accuracy. For example, overhead costs from different contractors may not be of the same scope or consistency due to differences in ways of doing business. Further, even data from the same contractor may differ significantly over time due to changes in the company's accounting system. Again, errors result.

In generating a risk-adjusted cost estimate, not only is basic CER uncertainty captured, as above, but technical risk and uncertainty as well. Unlike before, the Xs in each of the model's CERs are now regarded as stochastic. Technical, acquisition, and cost-estimating risks are now considered. Variables affected might include:

- Quantity of units to be developed or procured.
- Weight of a platform or system.

- External parameters such as the price of oil.
- System-to-platform integration challenges.
- Number of drawings.
- Number of SLOC (source lines of code) or percentage of SLOC reuse.
- Number of test flights.
- Key schedule milestones such as date of critical design review or date of first flight.
- Cost parameters such as learning curve rates, T1s (first unit costs), and percent award fee, assuming these variables are not already covered in uncertainty analysis.

Further, discrete risk events such as failure to effectively design a new aircraft engine or a new circuit card are captured here as well. As before, for each of these risk variables, probability distributions are estimated or selected, and Monte Carlo simulation is used to generate a probability density function.

Finally, the difference in mean values of the two probability distributions, risk-adjusted and baseline, represents cost risk. Senior leadership can then set budgets based on how much risk they are willing to tolerate.

The following sub-sections describe the process in more detail.

7.4 COLLECTING DATA FOR RISK ANALYSIS

Data is the raw material of risk and uncertainty analysis. It is critical to every estimate. Without good, solid data, whether based on historical analogies or on sound engineering understanding of the acquisition at hand, the risk and uncertainty estimate will be viewed as merely a guess or an opinion of the cost analyst. The more solid the data, the better will be the estimate.

At the start, it is important to understand the fundamental objectives of the programme, including requirements, scope, schedule, technical goals, and evolutionary phases. With this backdrop in mind, the following steps should be executed:

- Identify all potential variables in the cost model affected by risk and uncertainty. It is usually helpful to have these in a single input area in a workbook.
- Identify potential data sources for estimating risk and uncertainty for each of these variables. That is, identify various ways of trying to determine a variable’s type of probability distribution and its associated parameters such as high, low, and most-likely values. Options include:
    - Using statistical equations from the cost model that give estimated means and variances.
    - Using scorecards, and derivatives thereof.
    - Culling ideas and information from subject matter experts.
    - Finding good historical analogies.
- Identify correlations between stochastic CBS elements.
- Identify sources for cross-checks. These might include use of alternative methodology, comparisons with historical cost growth on similar programmes, and, time permitting, sanity checks for completeness and reasonableness with subject matter experts.
- Develop and execute a data collection plan.

The following sub-sections discuss specific techniques employed in gathering and analysing the information required to conduct risk and uncertainty analysis.

7.4.1 Techniques

Data collection techniques are conveniently grouped into these categories, although there is some overlap between the three:

- Use of scorecards and their derivatives.
- Use of historical cost data.
- Use of subject matter experts (SMEs).

7.4.1.1 Scorecards

Scorecards and their derivatives usually present a vector of numerical values from which SMEs choose to assess risk in a given area, such as schedule. Scales, which indicate probability of occurrence or amount of risk, might range from 1 to 10 or perhaps from 1 to 3. These numerical values are then translated into impact on cost.[6]

7.4.1.2 Historical Data

An excellent source of information on risk and uncertainty is historical data and its use in the cost estimation process. Least squares regression analysis, for example, automatically generates an estimate of the mean and variance of an equation's random error term. These values can be input directly, without modification, into the Monte Carlo simulation. Further, metrics on growth in key parameters such as lines or code or aircraft weight from start of development through initial operational capability are very useful in shedding light on possible areas of risk.

7.4.1.3 Expert Opinion

Risk analysts have traditionally used historical data as an information source in probability assessments, but sometimes the required data is quite difficult to obtain. An important factor, which often causes relevant data to be scarce, is that risk analysis typically deals with rare events. Furthermore, the systems under study often represent new concepts and technologies for which little or no experience exists. In risk analysis where there is little or no relevant historical data, expert judgment is frequently applied. In other words, expert judgment is typically appropriate when:

- Data is sparse or difficult to obtain.
- Data is too costly to obtain.
- Data is open to different interpretations, and the results are uncertain.
- There is a need to perform an initial screening of the problems.

An expert, in this instance, is a person with special knowledge or skills in a particular area. The selection of the expert is important for the accuracy of the results to be obtained. The following criteria may be used for the selection process:

- Experience in performing judgments and making decisions, based on evidence of expertise like degrees, research, publications, positions and experience, etc.
- Availability and willingness to participate.
- Impartiality.
- Inherent qualities like self-confidence and adaptability.

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[6] See **Cost Programmed Review of Fundamentals** (CostProf), Chapter 9, "Cost Risk Analysis," Society of Cost Estimating and Analysis, 2002, for an important discussion of scorecards, especially the advantages of interval versus ordinal ranking.

Further, culling of information from SMEs can be facilitated and made more rigorous by employing some of the following tools and procedures.

- **Checklists**. These can be based on experience of earlier programmes – risk issues can be identified and quantified through an examination of what occurred on previous programmes plus an overall understanding of the issues that are likely to be problematic on future programmes. These issues can be formalised into lists and structured in a way that suits the particular type of programme. New programmes can then be examined against the list and an opinion formed about each point raised.
- **Structured Interviews**. These would be held with responsible or knowledgeable staff, perhaps using the checklist as the basis. Interviews of this type are best done on a one-to-one basis, free of any hint of an inquisition. They can refine the perception of where difficulties may lie as well as drawing attention to areas that might not be covered in the checklists.
- **Brainstorming Sessions**. These are normally held with a group of knowledgeable staff in an atmosphere of free speculation and without peer criticism. People are invited to produce as many ideas as possible of the risks that might arise. This can lead to a very large number of ideas, some of which may be wild speculation. All risk ideas put forward have to be analysed and categorised into those that are real and need to be dealt with and those that are largely imagined or are extremely unlikely and can be ignored.
- **Assumption Analysis**. This is where all the basic assumptions are listed and challenged. This is often more difficult than it might seem as many assumptions are unspoken and simply never considered. They are things that are so familiar that they are taken for granted, even in new situations. Assumptions should be tested against both their importance to the programme overall and the likelihood that they might prove false. Any that cannot be unreservedly accepted as being valid are potential sources of risk and can be treated as such.

7.5 ESTIMATION PROCESS

As mentioned above, each of the factors, ratios, and CERs in a cost-estimating model is usually stochastic. The uncertain or random nature of these variables can be expressed as a probability distribution with a certain mean and variance. Combining the probability distributions of each of the variables in a large cost model for a major weapon system acquisition programme to obtain a total cost probability distribution cannot be done mathematically. The number of variables is simply too numerous and the resulting calculus too unwieldy. A good, statistically sound alternative is Monte Carlo simulation.

In this technique, a random sample is taken from the probability distribution associated with each CER and each risk variable. Based on the functional form of the factor or CER, arithmetic operations are performed to obtain a single estimate of the cost of that CBS element. This is done for each uncertain factor and CER in the model. Results are summed into a *single* estimate of the cost for the entire weapon system. This estimate, then, is one observation or experimental result out of an infinite number available. The procedure of random number selection and subsequent cost computation is then repeated thousands of times to develop a frequency histogram (or probability distribution) of total system cost.

7.5.1 Baseline Cost Estimate

In this step, input values such as a SLOC (Source Lines of Code) count, aircraft weight, and radar performance are regarded as deterministic. Values of each of these variables are plugged into CERs as fixed numbers. Figure 7-3 illustrates the process for one CER corresponding to one cost element. In this example, the CER represents the relationship between software development cost and the number of source lines of code. The relationship is curvilinear, as are those of many CERs in defence cost analysis.

Beyond a certain SLOC count, the software development project becomes so big and complex that the probability of success diminishes sharply and costs escalate precipitously.

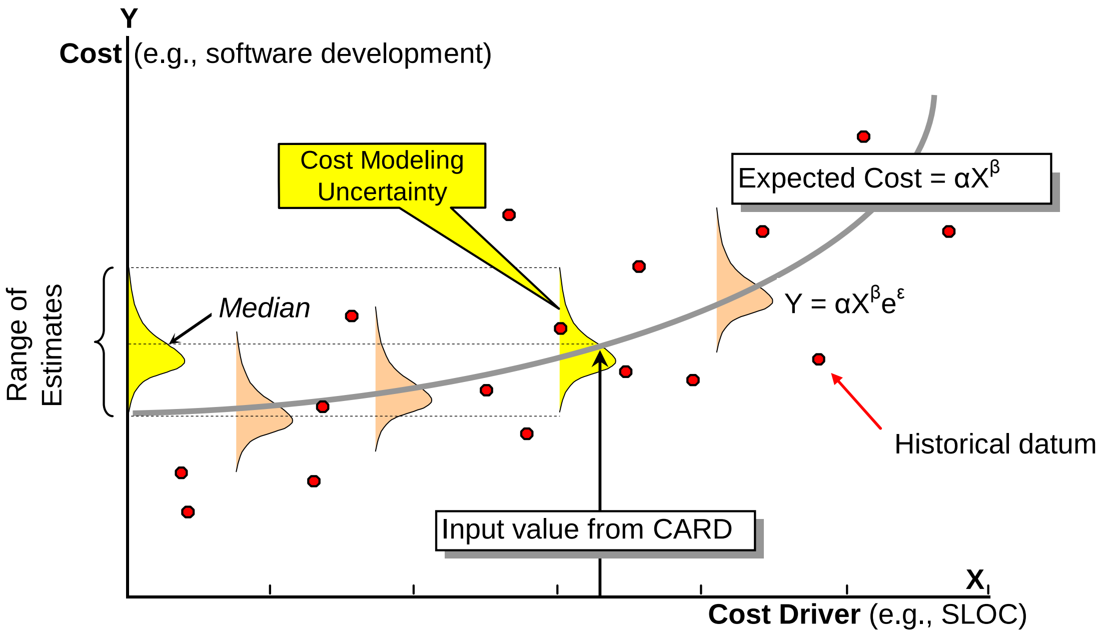

Figure 7-3: Baseline Cost Estimate.

To generate the **baseline** cost estimate, a fixed value for SLOC count is input into the CER. For this fixed value, there is an entire probability distribution of associated costs.[7] The distribution represents cost uncertainty. Cost, in this case, is log-normally distributed.[8] In the Monte Carlo simulation, the computer generates a random number for this distribution, based on the value of SLOC. An identical process is followed for other CERs (not shown here) in the model. Costs are aggregated for all CBS elements. The baseline cost estimate emerges after sufficient repetition of the process.

7.5.2 Risk-Adjusted Cost Estimate

The next step is to generate a risk-adjusted cost estimate.

As Figure 7-4 shows, input parameters such as a SLOC (source lines of code) count are now regarded as stochastic rather than deterministic. Hence, distributions for these parameters need to be chosen. These are often triangular. Most-likely values, defined by the mode in this case, may now differ from those values presented in the CARD (cost analysis requirements description). Once again, a Monte Carlo simulation is conducted. First, the computer randomly chooses a SLOC count from the triangular distribution, somewhere within the low to high range. These low and high values correspond to median values on the population relationship (or curve) between Y and X. For each of these median values, in turn, there is an

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[7] This is because the underlying relationship between cost, Y, and SLOC count, X, is stochastic. The relationship is specified by the equation $Y = \alpha X^{\beta} e^{\varepsilon}$, where α and β are population parameters to be estimated, e is the residual value and ε is a normally distributed random error term with mean 0 and variance σ^2_{ε}. This error term imparts uncertainty to cost.

[8] Interestingly, as Goldberger indicates, when a power-function form is used for a CER, attention shifts, "… apparently unwittingly, from the mean to the median as a measure of central tendency." That is, plugging a value of X into the CER yields an estimate of the *median* value of Y rather than the mean. This is a little known fact in econometric modelling and in defense cost analysis. See Goldberger, Arthur S., "The Interpretation and Estimation of Cobb-Douglas Functions," Econometrica, Vol. 35, July-October, 1968, pp. 464-472, for more details.

entire log-normal distribution of costs. The endpoints highlighted above represent the range of possible values of cost in the sampling simulation.[9] The frequency distribution illustrated on the Y-axis is the risk-adjusted cost estimate.

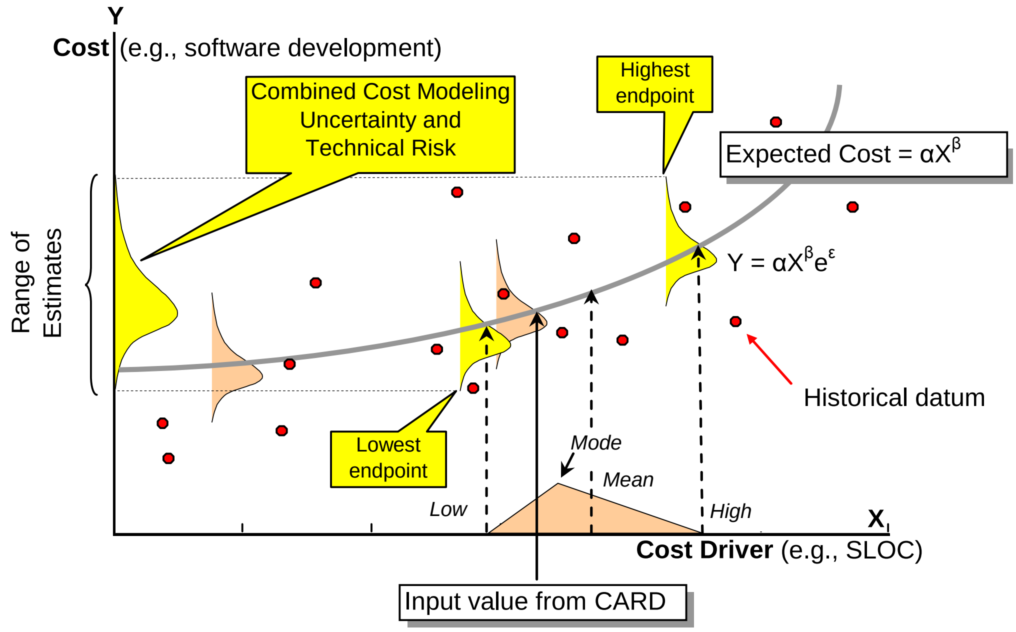

Figure 7-4: Risk-Adjusted Cost Estimate.

7.6 COST AND BUDGET RISK

7.6.1 Cost Risk

The baseline cost estimate contains modelling uncertainty while the risk-adjusted cost estimate contains both modelling uncertainty and technical uncertainty and risk. The risk-adjusted probability distribution will therefore have a higher mean value and a higher variance than the baseline estimate. Its distribution will typically appear flatter and more skewed to the right, as Figure 7-5 shows. The difference in mean or expected values of the two distributions is cost risk. This value is usually expressed in monetary rather than percentage terms. It accounts for the cost impact of unfavourable outcomes in a major acquisition programme such growth in lines of code or failure of a new computer chip to work correctly. Aggregate cost risk can be allocated to any cost breakdown structure element, as appropriate.

[9] More precisely, since the log-normal distribution extends to infinity, upper-bound costs illustrated here should be regarded as holding for some fixed percentile, such as the 99th.

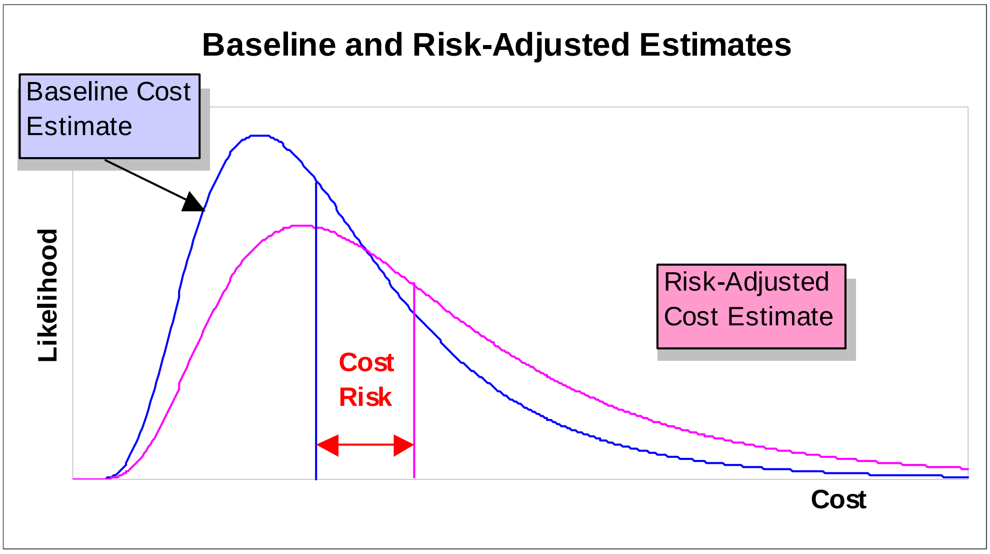

Figure 7-5: Cost Risk Analysis Output.

7.6.2 Budget Risk

Budget risk is the probability that the actual cost of a weapon system acquisition programme will end up exceeding a given budget, as Figure 7-6 shows. In this case, the budget is set at the mean value of the risk-adjusted cost estimate. Costs to the right of the mean are all legitimate possibilities, as are those to the left of the mean. Since the budget is finite, there's a certain probability it will be exceeded. The percentage of the area of the distribution to the right of the budget is defined as budget risk. It is usually expressed as a number such a 40%, or 50%, or 60%. The value of risk analysis is that it quantifies this probability. Decision makers can then determine what degree of risk to accept, given the value of the weapon system and given the values and risks of alternative systems in a warfighting portfolio. A low budget implies a high probability of an overrun while a high budget implies a low probability of an overrun. It's up to the decision maker to decide where he/she wants to set the budget.

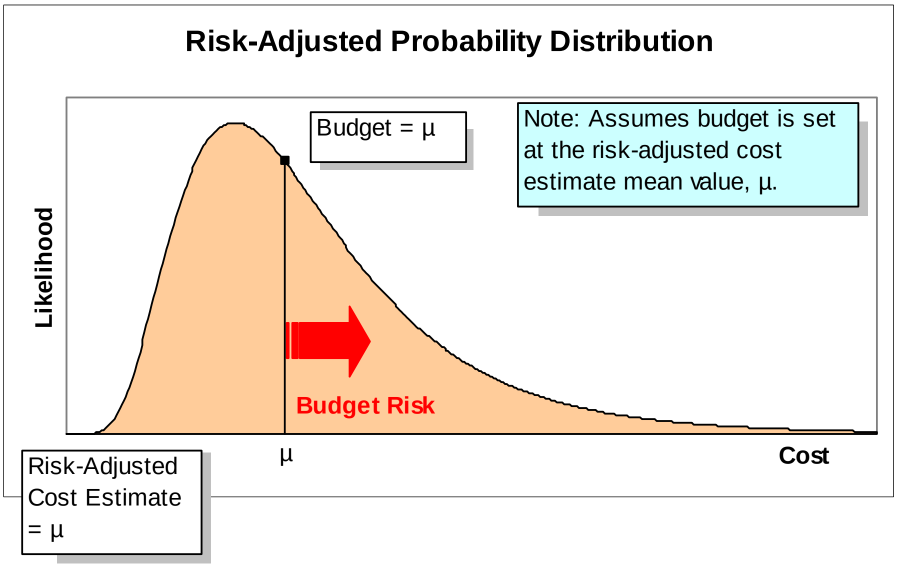

Figure 7-6: Budget Risk Analysis Output.

7.7 SENSITIVITY ANALYSIS

Another popular method for taking risk into account in generating life-cycle cost estimates is sensitivity analysis. This process, in its simplest form, measures the impact on cost of changing one or more key input values about which there is uncertainty. For example, a pessimistic, baseline, and optimistic value might be chosen for an uncertain variable, such as the slope of a learning curve. Then, an analysis could be performed to see how the life-cycle cost of the weapon system changes as each of the three chosen values is considered in turn, with all other factors held the same.

Further, a more complex analysis could be undertaken where values associated with several variables such as learning curve rate, degree of hardware commonality, and growth of out-year business base are grouped or bundled together to form pessimistic, baseline, and optimistic scenarios. For each scenario, a cost estimate is then generated.

A similar analysis can be conducted by varying a set of parameters from low to high and determining the impact on total cost of each. Results of this kind of analysis are often displayed in a tornado chart, as shown in Figure 7-7, where parameters are ranked according to their relative influence on cost.

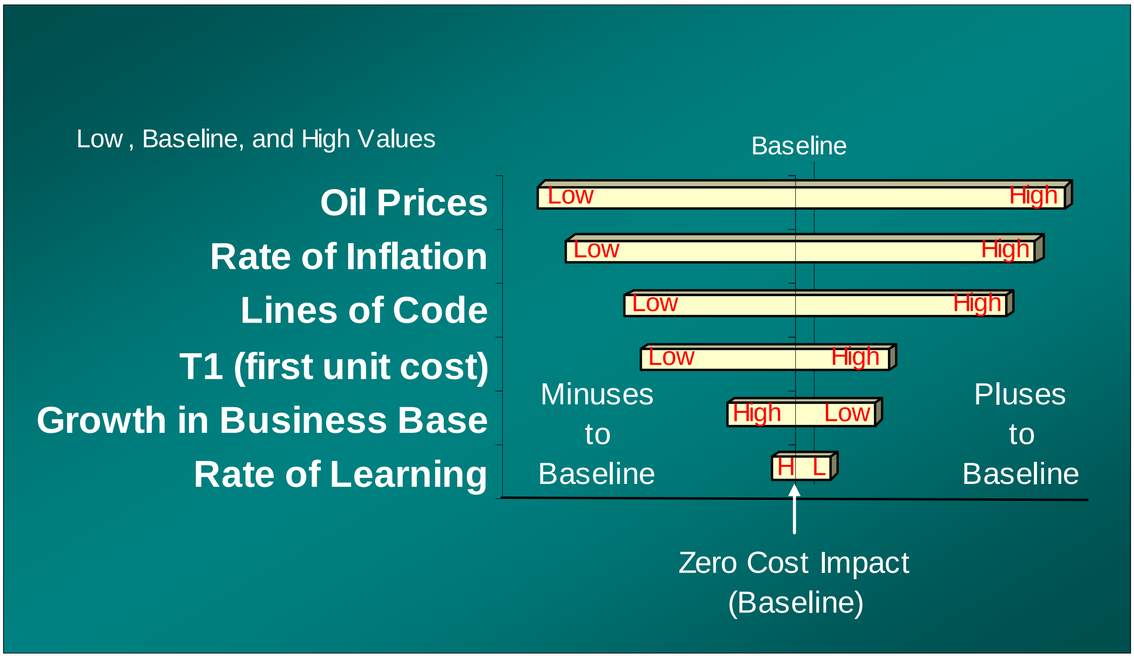

Figure 7-7: Example of Sensitivity Analysis Tornado Chart.

Finally, a shortcoming of sensitivity analysis is that it makes no statement about the probability that a low, baseline, or high value of a parameter might be obtained. Nevertheless, the technique can be performed rather quickly and inexpensively. Experience suggests that in many concrete applications it provides a reasonable and relatively trustworthy estimate of life-cycle costs.

7.8 FINDINGS

This sub-section describes a summary of the methods and models related to risk and uncertainty that are being used by the participating nations, based on the analysis of the matrices completed by the study participants and introduced in Chapter 1. Figure 7-8 shows the results of this analysis graphically.

Risk		Mission need	Pre-feasibility	Feasibility	Project Definition	Design & Developm.	Production	In-service	Disengage-ment
Methods	Expert opinion	●	●	●	●	●	●	●	●
	Monte Carlo simulation	◒	◒	◒	◒	●	◒	◒	◒
	Sensitivity analysis	●	●	●	●	●	●	●	●
Models for risk analysis	In-house	●	●	●	●	●	●	●	●
	Commercial	●	●	●	●	●	◒	◒	◒
Models for uncertainty analysis	In-house	●	●	●	●	●	●	●	●
	Commercial	●	●	●	●	●	●	●	●

Legend

blank	*No nation*
○	*1 nation*
◒	*2-3 nations*
●	*>3 nations*

Figure 7-8: Summary of Methods and Models Used to Measure Risk and Uncertainty.

The findings at Figure 7-8 appear to show that risk and uncertainty analysis is widely used by NATO and PfP-nations. We all say that we are doing this. However, this figure does not present the whole story. Discussions in our Task Group showed something completely different. All nations are familiar with methods and models to be used for quantifying risk and uncertainty, but among NATO and PfP nations, the application of risk and uncertainty analysis varies widely. No NATO standard procedure is used or recommended. Collectively, the group of nations is certainly not guilty of Emerson's aphorism that "a foolish consistency is the hobgoblin of little minds[10]". Just the opposite seems to hold. We are widely inconsistent in the application of risk and uncertainty methods between nations, within nations, and even sometimes within the same organisation in a single nation!

More specifically, the survey results indicate that, sometimes, risk and uncertainty analysis is not undertaken at all in generating a life cycle cost estimate. Instead, single, point estimates are provided to the decision makers. At other times, when risk and uncertainty analysis is conducted, the two most commonly used techniques seem to be expert opinion and sensitivity analysis. Detailed risk and uncertainty modelling, such as Monte Carlo simulation, seems to be undertaken, with varying degree of frequency, by only two to three nations.

7.9 RECOMMENDED PRESENTATION OF RESULTS

Figure 7-9 presents a recommended approach for communicating results of a life cycle cost estimate to senior decision makers.[11] The top line shows a three point range of estimates, and conveys the idea that a cost estimate is not a single number, but rather a continuum or distribution of possible values.

[10] Essays (First Series) "Self-Reliance" by **Ralph Waldo Emerson** (1803–1882): "A foolish consistency is the hobgoblin of little minds, adored by little statesmen and philosophers and divines."

[11] U.K. Ministry of Defence and **Impossible Certainty**, RAND, 2006, pp. 84-86.

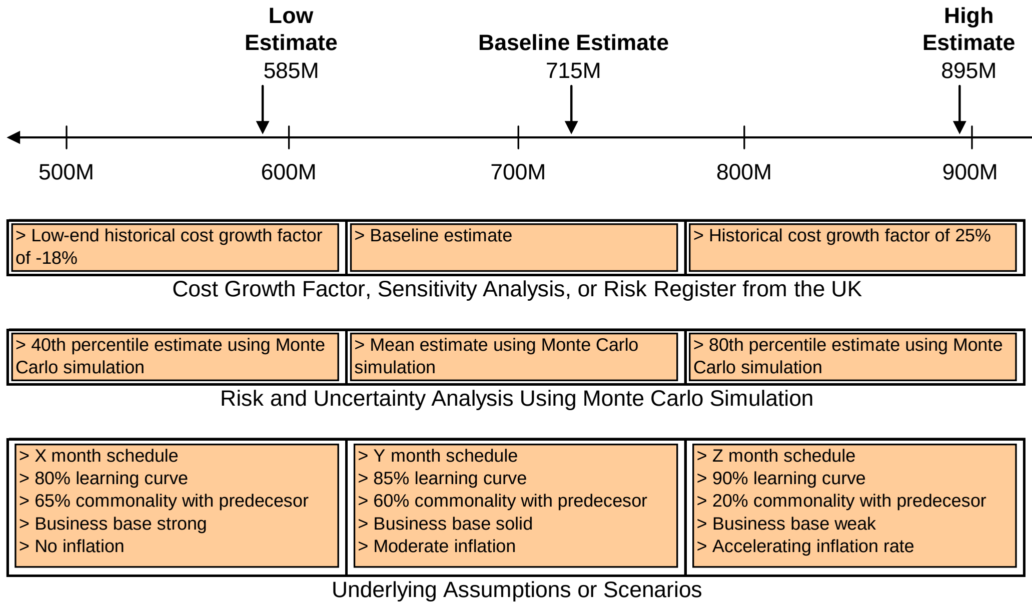

Figure 7-9: Recommended Presentation of Cost Estimating Risk Analysis.

Analysts can use one or more estimation techniques in performing risk and uncertainty analysis. Some of these are shown in the top two bars or sections of the figure. The bottom section, which should always be included in the presentation of the estimate, shows all of the assumptions or scenarios associated with the low, baseline, and high estimates. Including this section enables decision makers to see clearly the cost implications of events that can influence the outcome of an acquisition programme.

7.10 REFERENCES

[88] See www.dau.mil/gdbks/risk_management.asp to obtain a copy of "Risk Management Guide for [U.S.] DoD Acquisition".

[89] See http://www.ispa-cost.org/PEIWeb/newbook.htm to obtain a copy of the "Parametric Estimating Handbook" from the International Society of Parametric Analysts. See Chapter 11 for details on risk analysis.

[90] See http://www.scea-alabama.org/pubs.shtml to obtain a copy of "Cost Risk Analysis Without Statistics," Garvey, Paul, MITRE, October 2003.

[91] See http://www.sceaonline.org for details on how to order a moderately priced copy of "Cost Programmed Review of Fundamentals" (CostProf) from the Society of Cost Estimating and Analysis. See Chapter 9 for details on cost risk analysis.

[92] See http://ceh.nasa.gov/ to obtain a copy of NASA's "Cost Estimating Handbook." Various sections relate to risk and uncertainty analysis.

[93] Risk Analysis – A Quantitative Guide 2nd Edition, Dr David Vose, John Wiley & Sons, 2002.

[94] Project Risk Analysis and Management 2nd Edition, Association of Project Management, 2006.

[95] Impossible Certainty, Cost Risk Analysis for Air Force Systems, RAND Corporation, 2006.

[96] Daneshkhah, A.R. (2004), Uncertainty in Probabilistic Risk Assessment, University of Sheffield.

Appendix 1: Optimism Bias

In the absence of the time or resources required to perform the detailed analysis prescribed in this chapter, an alternative is to apply percentages to a bottom-line estimate, as shown below.

There is a demonstrated, systematic tendency for project managers to be overly optimistic. To redress this tendency cost analysts should make empirically-based adjustments to the estimates of a programme's costs, benefits, and duration.

These adjustments should be based on data from past, similar projects, and calibrated for the unique characteristics of the programme at hand. In the absence of a more specific evidence base, analysts are encouraged to collect data to inform future estimates of optimism, and in the meantime use the best available data.

The main aim of applying this guidance is to provide a better estimate of the likely life cycle cost of a major weapon system acquisition programme.[12]

Table 7-1 shows the percentage build up when using an "optimism bias" approach. These percentages should be added to the cost estimate when the relevant programme information is immature or not available.

Table 7-1: Optimism Bias Estimate Uplift Percentages

Project Information	**Relevant Percentage Uplift**
Complexity of contract	7%
Late contractor involvement in design	7%
Poor contractor capabilities	4%
Information Management	5%
Design complexity	10%
Degree of innovation	17%
Inadequacy of business case	18%
Poor management team	5%
Poor project intelligence	4%
Legislation/regulations	5%
Technology	18%

Figure 7-10 provides an illustration on the application of "optimism bias" in a programme review. It compares the known quality of the data (judged from the list above) added to the programme estimates against the stochastic output from a cost risk analysis utilising a three point estimate.

[12] A detailed description of the recommended adjustment ranges and a detailed approach is described in the "Supplementary HM Treasury Green Book" guidance on optimism bias, UK.

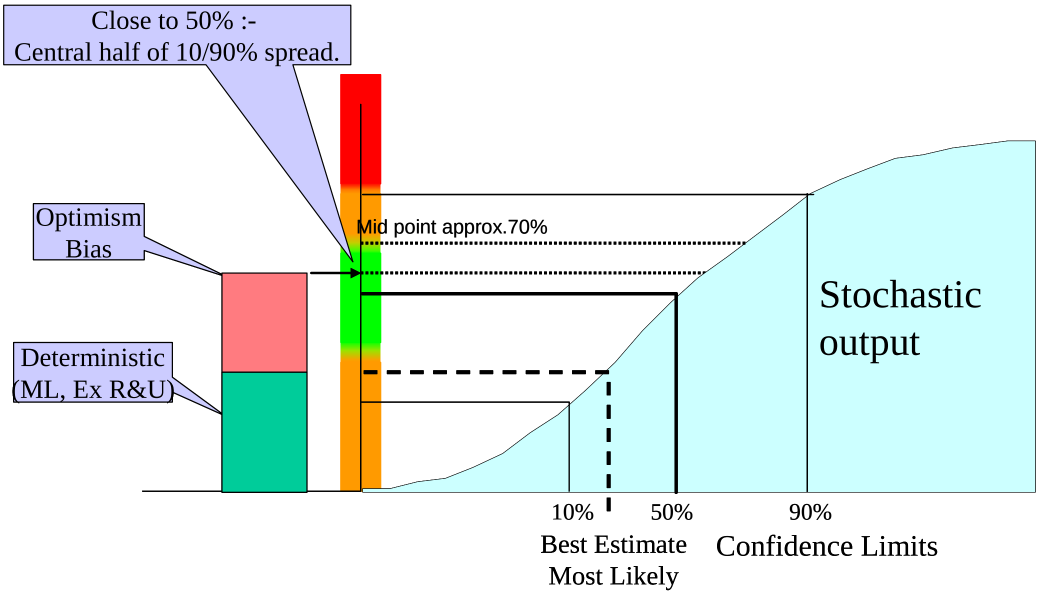

Figure 7-10: Application of Optimism Bias.

Chapter 8 – OTHER RELATED LIFE CYCLE COSTING ISSUES

This chapter identifies and discusses other issues that the cost estimator/analyst will have to consider in conducting a life cycle cost estimate.

8.1 TAXATION

Income tax and other tax effects on capital investments are significant and should be considered carefully from the early phases of a system's life cycle (e.g. during feasibility studies). Taxes are assessed as a percentage of taxable income, usually on a graduated basis: the higher the taxable income, the higher the tax rate. Taxes reduce the income from investments.

A typical example for taxation, first introduced in France in 1954 and later extended to several Western European countries is the Value-Added Tax (VAT). The following is an example of the application: as a material moves from the raw material stage to the finished product, whenever it changes ownership, the product is taxed at a fixed rate on the value of the product after all the costs of manufacture (materials and other expenses) have been deducted.

The advice from legal advisors at the NC3A (NATO Command, Control and Consultation Agency) suggest that the following statement is included in the Contract Conditions.

- Bidders are informed that the Purchaser, by virtue of his status stipulated in the provisions of the NC3O (NATO Consultation, Command and Control Organisation) Charter, Article 67(c)(3), is exempt from all direct taxes (including VAT), and all customs duties on merchandise imported or exported. This provision reads as follows:

  "Each participating nation undertakes to grant to NC3A under the terms of Articles 9 and 10 of the Ottawa Agreement, exemption from all direct taxes (except rates, taxes and dues which are no more than charges for public utility services) from the taxes on the sale of movable and immovable properties, and from customs and excise duties in respect of equipment imported or exported by NC3A or its appointed agents."

- The bidder shall therefore exclude from its price quotation all taxes, duties and customs charges from which the purchaser is exempted by international agreement. This practice could however differ among the member nations.

The text above provides guidance on how NATO is treating the issue of taxation within NATO programmes. **However, in individual nations, the regulations may be different and it is recommended that advice should be sought with the appropriate national authorities**.

8.2 DISCOUNTING AND PRESENT VALUE

8.2.1 Discounting

Discounting is a technique used to compare costs and benefits that occur in different time periods. It is a separate concept from inflation, and is based on the principle that, generally, people prefer to receive goods and services now rather than later. This is known as time preference.

Most cost comparison techniques take into consideration the time value of money: e.g. a Euro today is worth some amount less in the future. For comparison purposes, future expenditure, occurring at different points in time, must be adjusted to a common point in time. This adjustment to a common point in time is

called discounting or present value analysis. Discount factors can be calculated once an interest rate and period of analysis is determined. These discount factors indicate the present value (today's value) of a Euro, Dollar. GB Pound, etc., expended at the end of each respective year (assuming end of year discounting is used). Therefore, discounting converts various cash flows occurring over time to equivalent amounts for differing interest costs and the time value of money resulting from expenditures over varying time periods.

Recommended discount rates are usually determined by a nation's Treasury Department and must be used consistently on all programmes. Calculating the present value of the differences between the streams of costs and benefits provides the Net Present Value (NPV) of an option. The NPV is the primary criterion for deciding whether government action can be justified.

8.2.2 Net Present Value

The present value (PV) of a stream of expenditures is the sum of discounted Euros (or other currencies as applicable) over the life of a programme. The following data is needed before beginning the PV process:

- **Base Year.** The base year is the year to which all costs are discounted. This is usually the same year that costs begin to accrue for any alternative.
- **Period of Analysis.** The period of analysis is normally the time from the start of a programme to the end of the mission requirement. In most cases this will coincide with the economic life of a project as described below:
  - The economic life of a project is the period of time over which the benefits to be gained from a project may reasonably be expected to accrue.
  - Benefits from a project are limited ultimately by its physical life. This is the period a facility or piece of equipment can be used before it is exhausted in a physical sense, that is, unable to perform its stated mission. The economic life of a project is further limited by its technological life; that is, the period before improved technology makes the building, machine, etc., obsolete. Military or political considerations that may suggest benefit accrual for a much shorter period may further limit the economic life of a project. Ways in which economic life can be determined include policy, management judgement, Government or industry standards and experience.
- In general, the economic life will be measured against a stipulated level of threat, or represent the period during which a given mission or function is required or can be supported. Once the base year and period of analysis has been determined, the PV is calculated using the following procedure:
  - Determine in what years the expenditures for the alternative will be made.
  - Select a discount rate appropriate to the period of analysis and list the discount factor for each year, using either year-end or mid-year discount factors. Specify and document which one is being used.
  - Multiply each yearly cost by its discount factor to get discounted currency for that year. Use the constant currency rate if your cost basis is in constant currency (as will normally be the case); otherwise use the current rate.
  - Sum the annual discounted currency to get a total PV of costs. Perform similar calculations for quantifiable benefits. The difference between the totals of PV benefits and costs will be the net present value of the project.
  - If there is a concern that the preferred alternative may change if a different discount rate is used, recalculate the results, varying the discount rate to see at what point (if ever) the preferred alternative changes. This will provide additional insight for the decision makers as they weigh the alternatives.

8.2.2.1 Example

If the government discount rate is used to determine the level of government investment spending that will maximise inter-generational social welfare, the use of risk premiums (individuals, companies and market risk) are indisputable. However, it is a formidable task to implement such an approach because of problems associated with identifying the value of the social rate of time preference. Some alternative approaches are discussed below:

- Step (a) – The use of the consumer rate of interest as the social rate of time preference can be justified only in very special circumstances; the ethical issues involved in choice of a social rate of time preference are not easily resolved.
- Step (b) – There seems to be a consensus that there can be a multiplicity of social discount rates depending on the nature of the finances, risks, and the degree of spill over effects of a given programme.
- The opportunity cost school approach can be derived as a special case of trying to introduce market risk principals.
- The shadow price approach is formally equivalent to the opportunity cost approach. Although it uses a uniform discount rate (social rate of time preference), the approach adjusts the special features of individual cases by the choice of multipliers to compute consumption-equivalent costs and benefits.

On the other hand, if the discount rate is used to filter government programmes rather than to determine the level of government investment expenditure needed to reach some societal optimum, then the existing theories do not adequately address the problem. In this case, the government opportunity cost rate (risk free rate/State bonds [say 10 years]) is the better choice.

The role of government in (a) is highly idealised. In reality, the level of government investment spending is the result of a complicated political process in which economic efficiency is only one of many factors at work. ***The recommended approach is step (b).***

8.3 EQUIVALENT ANNUALISED COSTS

Annual value is a measure of costs in terms of equivalent equal payments made on an annual basis. The equivalent annual cost of a programme is calculated by dividing the net present value of the programme by the cumulative discount factor for the number of years of programme life. An alternative approach would be to multiply the net present value by the appropriate annuity factor, where the annuity factor is the reciprocal of the cumulative discount factor.

Annual value analysis often involves fewer calculations than present value analysis if differing lives are under consideration for investment alternatives, because annual value implicitly assumes equal replacement values and the least common multiple of the different lives without extra calculations. Consequently, the major advantage of the annual value method of comparing alternatives on the basis of periodic payments is that the complication of unequal lives of competing alternatives is automatically taken into account and the same selection decision as the present value technique will be yielded.

For example, consider the appraisal of a programme which has examined two options to achieve the required objective:

- The NPV cost of Option A over a 5 year life is £10 m.
- The NPV cost of Option B over a 7 year life is £12 m.

The EAC (Equivalent Annual Cost) of Option A is calculated by dividing the NPV of £10 m by the cumulative discount factor for 5 years of 4.5151 (assuming a discount rate of 3.5%) to give £ 2.215 m. Alternatively, the NPV of Option A could have been multiplied by the 5 year annuity factor of 0.2215 (assuming a discount rate of 3.5%) to give the same EAC of £ 2.215 m.

The equivalent annual cost of Option B using the cumulative discount factor of 6.1145 or the 7 year annuity factor of 0.1635 is £ 1.962 m.

Option A has the lower NPV cost. However, selecting the preferred option by the NPV criteria would result in a poor choice. As the two options have different lives, it is important to base the decision on Equivalent Annual Costs in order to compare like with like. Option B should be selected as it has the lower EAC.

8.4 VARIATION OF PRICE

Under conditions specified in contracts, there may be provision for revision of contract prices. A typical occurrence is a contract of a duration longer than a specified limit (e.g. 2 years), concerning the procurement of advanced technology defence systems through an international cooperation programme.

In such cases, prices agreed at certain economic conditions are escalated to the period of actual performance.

The formulae to be used for this purpose contain a material and wage/salary related portion of the price as well as indices in accordance with which the basic values have to be escalated. Price indices are percentages of annual increases in costs for a given economic sector. In the different countries, such price indices by sectors are published by governments or by specialised trade and industry associations, with an official acknowledgment.

As soon as the minimum specified duration is exceeded, contract prices can be revised taking into account a price index applicable to labour rates (e.g. in connection to productivity improvements and in accordance with the annual increase in wages and salaries) and a price index applicable to specified classes of materials (e.g. steel, plastic, etc.). The source and the specificity of the indexes used must be clearly established at the time of the contract.

The following equation provides a generic price revision formula:

$$P_1 = (P_0 /100) * [a + b * (M_1 / M_0) + c * (L_1 / L_0)]$$

where:

P_0	=	*Initial price as stipulated in the contract*
P_1	=	*Price payable under revision clause*
a	=	*Percentage of price excluded from adjustment (e.g. 5 to 15 per cent)*
b	=	*Average percentage of labour cost (e.g. 45 to 65 per cent)*
M_0	=	*Price index of specified materials (initial date)*
M_1	=	*Price index of specified materials (revised)*
c	=	*Average percentage of materials cost (= 100 – a – b)*
L_0	=	*Average labour rate (initial date)*
L_1	=	*Average labour rate (date of revision)*

Mathematical formulae used in price revision can be perceived as a reasonable compromise between parties in a long-term agreement, as well as an interesting tool to control future costs. Fixed elements within the price revision formulae have to be negotiated on a case by case basis, e.g. taking into account inflation constraints.

Chapter 9 – NEW DEVELOPMENTS IN LCC ANALYSIS

Over the duration of the SAS-054 study a number of associated requirements that will impact on cost analysis have been identified. However, although there is some understanding at this stage, the actual requirements and therefore the likely scope of the change in terms of the demand on cost analysis is not clearly known.

The topic of joint war-fighting[1] (or operational activities) is becoming more important to NATO. At present, there is insufficient information on how to evaluate the situation where a number of discrete assets share the information/data to provide a total capability solution. The costing of the assets themselves is straightforward, but when combined the interpretation on apportionment where multi-mission systems feed into several capabilities is not clear.

To more effectively manage scarce defence resources, several nations are initiating efforts to analyse the costs, capabilities, and risks of entire portfolios of assets in a joint war-fighting environment.[2]

Viewing capabilities across the entire portfolio of assets enables decision makers to make better informed choices about how to reallocate resources with the ultimate goal of delivering needed capabilities to the joint force more rapidly and efficiently[3]. Capability portfolios are intended to serve as a basis for strategic level trades by senior decision makers, as depicted here in Figure 9-1.

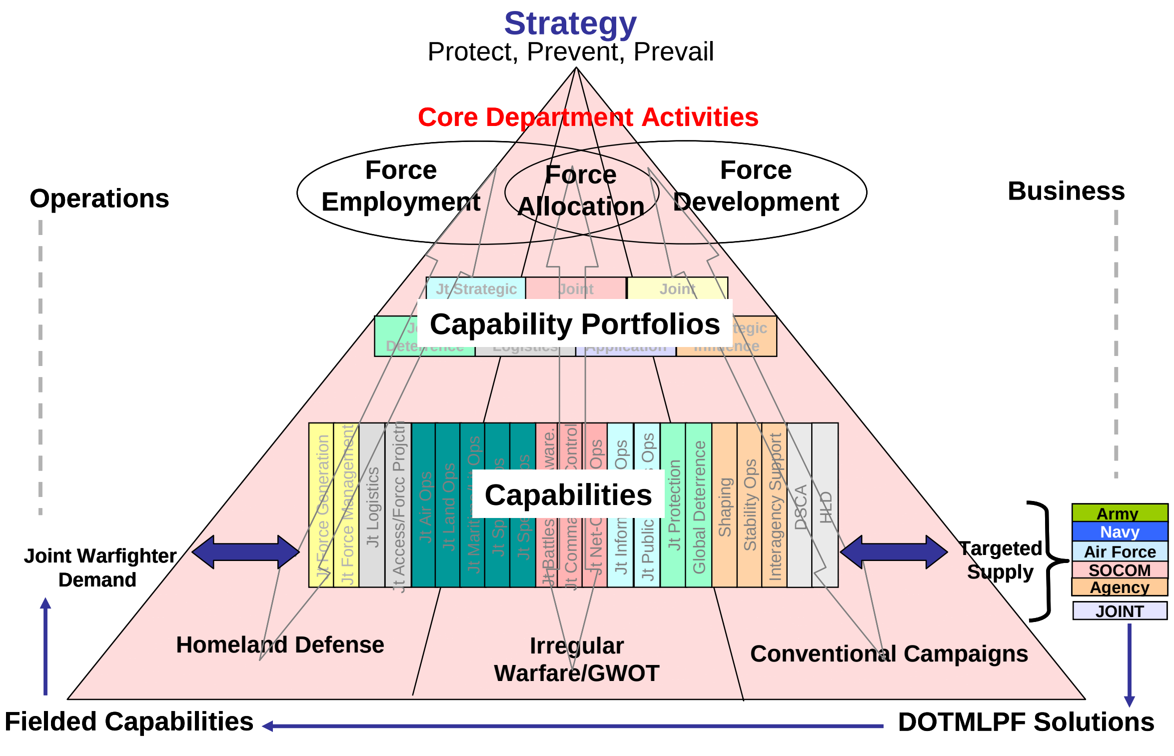

Figure 9-1: Prioritising using Portfolio Analysis.

[1] NATO report entitled 'Backgrounder' interoperability for joint operations.

[2] The 2001 Quadrennial Defense Review (QDR) in the United States directed DoD to shift from threat-based planning to capability-based planning. Further, the 2006 QDR reaffirmed the shift to capabilities-based planning and directed the use of joint capability portfolios to manage DoD resources.

[3] Draft letters from the Undersecretary of Defense [U.S.] for Acquisition, Technology, and Logistics on four pilot programs for conducting portfolio capability analyses, July 2006.

In the United States, four pilot programmes or test cases are currently underway for performing portfolio capability analyses: Joint Logistics, Joint Battlespace Awareness, Joint Command and Control, and Joint Net-Centric Operations. Further, last year, the Department of the Navy in the United States conducted a pilot programme for portfolio analysis of mine countermeasure assets.

Portfolio analysis, according to one of several possible implementations, would be conducted in conjunction with a concept decision review early in the planning, programming, and budgeting cycle, that is, prior to concept refinement in the U.S. acquisition framework. In this paradigm, an entire portfolio of assets, large and small alike, would be analysed. Gaps would be identified by the combatant commands (war-fighters) and trade-space would be offered as an option for at least partly funding these gaps. Further, ideally, a menu of portfolios would be generated from which senior decision makers could choose to meet strategic requirements.

In terms of cost estimating for NATO and PfP countries, these guidelines are suggested:

- Generate costs in constant-year monetary units (e.g. dollars or Euros).
- Generate life cycle costs.
- Depending on where a system or concept falls in the life cycle, this might include estimates of science and technology costs, development and production costs, operating and support costs, and disposal costs.
- Generate costs for a ten or twenty year period.
- Ensure that an entire portfolio of war-fighting assets is included in the analysis. Small systems are important, too, and completeness is essential.
- Perform risk and uncertainty analysis.

For the NATO and PfP cost community, this shift in emphasis from the analysis of individual programmes at key gates or milestones to the analysis of entire portfolios of assets, some of which are merely concepts rather than programmes, will entail:

- Earlier involvement in the planning process.
- Use of high level cost estimating relationships based on technical and performance characteristics of proposed systems.
- Extensive data gathering as well as the creation of new databases linking systems to capabilities.
- Use of new methods and models for analysing the costs, capabilities, and risks of a large group of proposed and existing assets rather than individual systems.

It is recommended that further study be conducted to provide a better understanding of the processes and application to the benefit of NATO and PfP nations.

9.1 REFERENCE

[97] Transformation of analytical tools – using portfolio analysis techniques in defence applications, Capt J. Field USN, and Dr B. Flynn, DoD Comptroller magazine, September 2005.

Chapter 10 – ENHANCE WORK SAS-028: CBS

10.1 INTRODUCTION

The SAS-028 Task Group related to cost structures and life cycle costs for military systems developed a NATO generic cost breakdown structure and associated definitions that can be used by any military programme to construct its own bespoke and programme specific cost breakdown structure.

It has been found that most nations have not adopted the generic cost breakdown structure reported in SAS-028 as their national life cycle cost breakdown structure. However, the NATO generic cost breakdown structure has been applied on specific programmes and some areas of enhancement are suggested.

10.2 RATIONALE

The application of the outputs of the report has shown that some difficulties had been met when the aggregation of the cost elements was performed (application of the construction of CBS Chapter 12 of the RTO-TR-058 report). In fact, the coding proposed in the report during the identification process of the cost elements (Chapter 9 of the RTO-TR-058 report) allowed the definition of a CDB (cost database). This coding was very useful for the identification of the three dimensions (Activity, Product and Resource) and the phase of the programme, but it could not easily define particular positions of specific cost elements inside the cost breakdown structure.

Although the NATO GCBS coding was a useful starting point it appeared that the different stakeholders evaluating the life cycle costs also needed (due to financial provisioning) a simple codification in order to identify where the various cost elements were within the cost breakdown structure. The following example provides an explanation on this issue:

Consider the cost element 'total contractor labour costs for manufacturing rework on the air vehicle's air/speed brakes', it is coded 6.1.1.5.2.1.1.1.1.8 (see Chapter 9 of SAS-028 report):

- The first field is related to the Phase (Production generic code 6).
- The second field is related to the Resource (Contractor Labour generic code '1.1').
- The third field is related to the Activity (Rework Modification generic code '5.2').
- The fourth field is related to the Product (Main System generic code '1').
- The fifth field is related to the Product Detail (Air Speed Brake standard or customised code, here, 1.1.8).

This coding structure does not help the non-expert to understand or find where a specific cost element is within the overall cost breakdown structure. It is therefore proposed to create:

- A 'generic hierarchy' of the cost breakdown structure with an incremental coding.
- A new presentation of the generic cost breakdown structure form allowing the link between the CDB and cost breakdown structure coding.

10.3 GENERIC HIERARCHY

This generic hierarchy is based on the cost breakdown structure activities defined in Chapter 8 of the RTO-TR-058 report. Figure 10-1 shows this generic hierarchy. The cost aggregates are defined up to the second level.

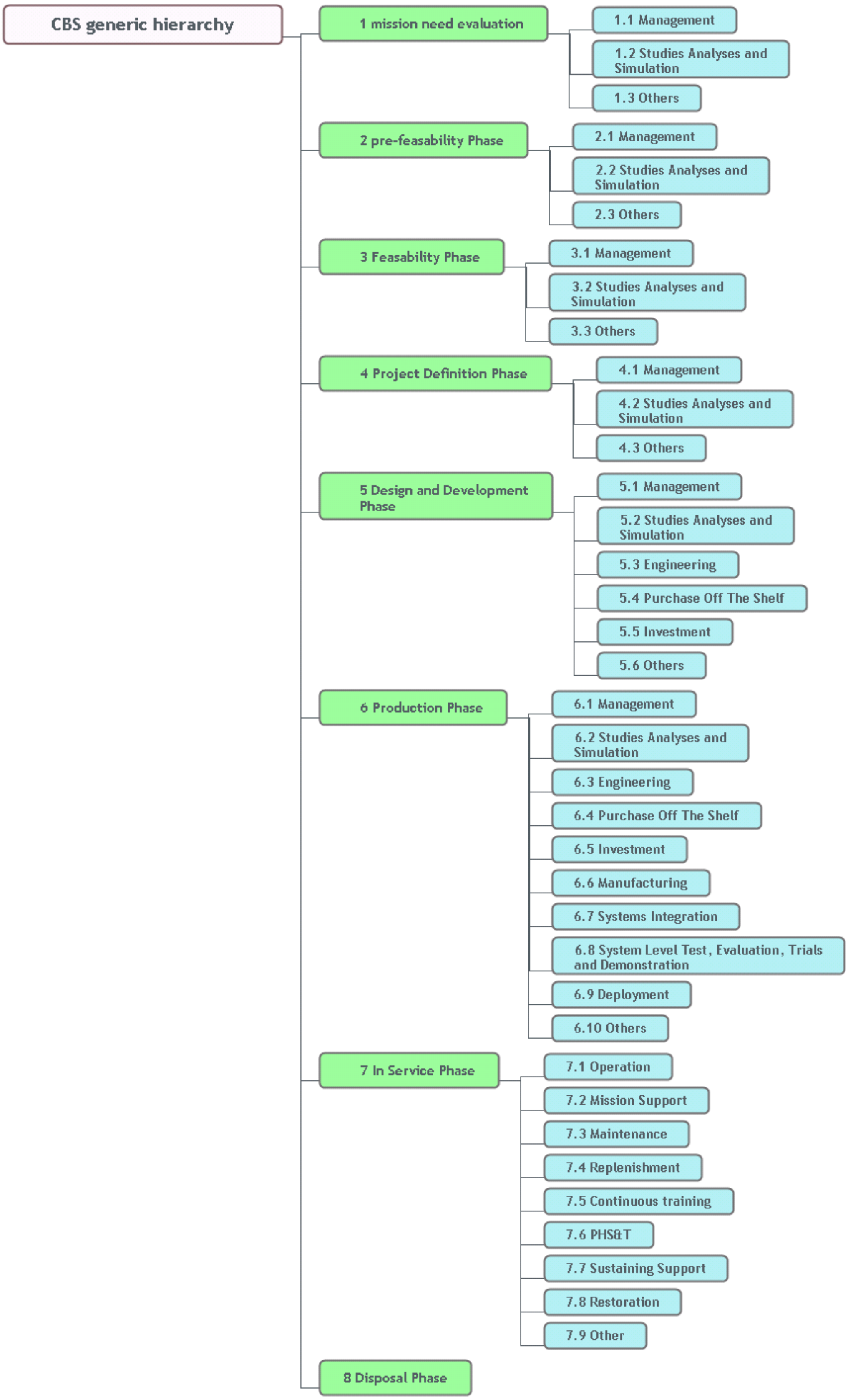

Figure 10-1: Proposed Generic Hierarchy Cost Breakdown Structure.

Once this generic hierarchy and its related coding have been set up, the different cost elements can be assigned to the appropriate cost aggregate. A coding related to the cost breakdown structure (incremental) could therefore be attributed to these cost elements.

Consider the same example as above and assume that this cost element is the first of the appropriate cost aggregate, it could be coded 6.7.1 in the cost breakdown structure as it is related to the production phase/system test and evaluation (6.7). Therefore, for communication purposes between the stakeholders, the codification would be 6.7.1 instead of 6.1.1.5.2.1.1.1.1.8.

If this structure is not uniformly adopted by all the nations then some form of mapping will have to be conducted to meet all the national and multi-national life cycle cost reporting requirements.

10.4 GENERIC COST BREAKDOWN STRUCTURE FORM

In the SAS-028 report, there are two possible types of presentation (table and list) proposed. It is suggested that the introduction of the above described coding in the table form is conducted as well as the identification of the different dimensions for each cost element. The figure below shows an example of this presentation. This presentation is given for a specific cost aggregate, but it is also applicable to the other cost aggregates.

Consider the in-service phase/maintenance (7.3) and then consider three different cost elements:

- Level 1 maintenance government labour cost for the main system.
- Level 3 maintenance contractor labour cost for the main system.
- Level 3 maintenance contractor material cost for the main system.

The presentation for this aggregate is given in the following matrix:

CBS coding

	Phase	Resource	Activity	Product
7. In Service Phase				
7.3 Maintenance				
7.3.1 Level 1 government Labour	7	2.0	3.1	1
7.3.2 Level 3 Contractor Labour	7	1.1	3.3	1
7.3.3 Level 3 Contractor Material	7	1.2	3.3	1

CDB coding

Figure 10-2: Example of Aggregated Cost Elements.

10.5 DIMENSIONS

Leading on from the presentation above, it is suggested that an additional dimension could take into account the nation dimension in multi-national programmes. The cost sharing between the nations should be identified in the life cycle cost model, therefore the distinction of the cost elements according to the nations should be set up in the cost breakdown structure.

In addition, in order to be more precise in terms of time, it is suggested that customisation for each phase dimension in the payment profiles should be determined in accordance with the specific requirements of the programme.

For example, during the production phase, the deliveries of the systems could last many years (particularly in multi-national programmes), therefore the payment schedule could be different from one delivery to another. This would lead to different payment profiles related to the different deliveries.

Taking account of these profiles within the cost breakdown structure could improve the presentation of individual budget forecasts.

10.6 RECOMMENDED ENHANCEMENTS TO THE NATO GCBS

The NATO Generic Cost Breakdown Structure developed by the SAS-028 Task Group does not allow the identification of the Life Cycle Cost results over time and the National contribution in case of multi-national programmes. Therefore, it is recommended to include two dimensions in addition to the Activity, Product and Resource dimensions:

- Time phasing; and
- National contribution.

As the coding of the Generic Cost Breakdown is complex for non-experts, it is recommended to adopt a Generic Hierarchy for the GCBS.

Chapter 11 – CONCLUSIONS

11.1 GENERAL

The results of life cycle costing must, whatever the phase of the programme, contribute to the process by which managers can make the best decisions on options presented to them. These options can include evaluation of future expenditure, comparison between alternative solutions, management of existing budgets, options for procurement and evaluation of cost reduction opportunities. Life cycle costing is also used for affordability assessment and determining the cost drivers associated with the Key Performance Indicators or Key User Requirements.

There are many methods and models available to conduct life cycle cost analysis. It was important to understand the applicability and boundaries of each method and model in order to use them appropriately. The core objective of the SAS-054 Task Group was to understand NATO and PfP nations' methods and models and to promulgate best practice throughout the life cycle.

11.2 REVIEW OF COST FORECASTING METHODS

Most cost estimates require the use of a variety of methods. A different approach may be used for each area of the estimate so that the total system methodology represents a combination of methods. Sometimes a second method may be used to validate the estimate.

When choosing an estimating method, the cost estimator must always remember that cost estimating is a forecast of future costs based on a logical interpretation of available data. Therefore, availability of data will be a major factor in the estimator's choice of estimating methodology.

The best combination of estimating methods is one which makes the best possible use of the most recent and applicable historical data and systems description information and which follows sound logic to extrapolate from historical cost data to estimated costs for future activities.

The report has captured all the key estimating methods and provided examples to demonstrate their applicability. For consistency, both the methods and models have been categorised as Optimisation, Simulation, Estimation and Decision Support.

The findings at Figure 4-4 clearly show that in order to generate a cost estimate all participating nations use many methods across each of the phases considered.

The findings confirm that all nations used a similar process to develop life cycle cost estimates; that the quality of the available data nearly always determines the method to be employed. In addition the type of study (strategic planning, options analysis, simulation and traditional estimating) and the life cycle phase also influence the process and the appropriate estimating method.

11.3 REVIEW OF COST FORECASTING MODELS

All nations use some form of in-house developed model for life cycle cost analysis. The majority also use commercial cost estimating models. A few nations do not use any type of commercial model; instead they rely totally on in-house developed models and/or other types of methods such as expert analysis.

Nearly 40 different models have been identified in the matrices. Almost half of them are commercial models and the remainder have been developed in-house. There are differences between the in-house

models, but one common feature is that many are developed in a spreadsheet environment and are often tailored for each specific programme. The in-house models are generally only used by the nation that has developed the model.

The findings at Figure 5-1 show clearly that models for estimation are the preferred models for life cycle cost analysis throughout the phases. In addition to models for estimation, models for decision support are used in the earliest phases and models for optimisation and simulation later on.

In order to provide verification of the life cycle cost estimate, it is good practice to use more than one model. Where sufficient data is available, the use of models for simulation and/or optimisation to supplement the overall life cycle cost model should be adopted. The use of multiple methods and models should always be evaluated on a cost-benefit basis ensuring that the added value provided from life cycle cost analysis is maintained.

11.4 GUIDELINES FOR THE COLLECTION AND UNDERSTANDING OF COST RELATED DATA FOR NATIONAL AND MULTI-NATIONAL PROGRAMMES

In terms of time, effort, and resources consumed, collection of data is a major part of a life cycle cost study. Life cycle costing is a data driven process, as the amount, quality and other characteristics of the available data often define what methods and models can be applied, what analyses can be performed, and the results that can be achieved.

As a system progresses through the life cycle, the types of data available evolve in a number of ways. As this in turn defines the task of data collection and the life cycle costing process in general, it is important to be conscious of these developments.

First and foremost, the amount of data available increases as the system becomes better defined. Obviously, very little is known about the end system when a project begins and all that exists is an identified capability gap or a general concept, whereas, when a system is in-service, the system and its environment can be documented in almost infinite detail.

Unfortunately, because uncertainty, risks, and opportunities decrease as the life cycle progresses, the need for knowledge is greatest at the earliest stages. This means that more time and resources should be allocated to the data collection effort during the earlier stages of the life cycle in order to develop an acceptable and auditable life cycle cost estimate.

Exchange of data between ERP systems and databases can be a cumbersome and time consuming affair if data formats and data models differ. It is therefore beneficial to have generally accepted and well documented standards. One such is ISO 10303-239 which has been put forward by NATO to be adopted as a STANAG. In the long term, PLCS has the potential to be an important tool to help collect and exchange high quality, well documented data. However, the PLCS is a very large and technically complex mechanism, and implementing PLCS would be a huge undertaking for any organisation. Alternative, ad hoc solutions in the form of agreed upon and documented templates, etc., may be used, but this makes the data harder to use at a later date for other projects or purposes. When possible, officially defined and accepted standards are preferred.

It is recommended to have previously agreed upon and well documented templates or standards for data to be provided by contractors and suppliers. Furthermore, particular care must be taken to secure that the data received from contractors, or other sources with a vested interest in a programme, are accurate and unbiased. The UK MDAL (Master Data and Assumptions List) is one well documented mechanism for

ensuring that all stakeholders buy into a common and clearly stated understanding of the project and the system of interest. A similar function is fulfilled for major acquisitions of the US DoD by the CARD (Cost Analysis Requirements Description). Furthermore, the US DoD has developed the CCDR (Contractor Cost Data Reporting) and SRDR (Software Resources Data Report) systems for accumulating actual contractor costs necessary to analyse costs efficiently and effectively. While data collection through formal reports such as CCDRs and SRDRs is extremely important and beneficial, there is still no substitute for taking the time to understand and verify the accuracy of historical information, and the programmatic context in which it was obtained.

11.5 TREATMENT OF UNCERTAINTY AND RISK

History has shown that cost estimates tend to be low – only about 10% of all programmes come in under or on budget. Because of this, cost estimates need to be adjusted for risk. Mistakes happen during estimation, schedules slip, technical difficulties arise, assumptions prove false, missions change, or the proposed hardware or software solution turns out not to meet the needs of the joint war-fighter. Because of all of these factors, risk needs to be included so that the analyst truly conveys to decision makers the uncertain nature of the estimate.

There are a wide variety of methods and models available for conducting risk and uncertainty analysis of life cycle cost estimates of weapons systems. These include sensitivity analysis, risk registers from the U.K., and detailed Monte Carlo simulation. Each, if used properly, can yield scientifically sound results. However, based on our collective experience in cost estimating within the government and in the private sector, it's fair to say that the sophistication and underlying theory of many popular models often far exceeds the quality of the basic data inputs. There is simply no substitute for taking the time and effort to understand the technical risks and challenges in developing and producing sophisticated defence systems.

The most important part of the process of estimating risk and uncertainty, and probably the most difficult, is data collection and analysis. All the variables in the cost estimating model potentially affected by risk and uncertainty first need to be identified. These variables often include simple ratios and factors as well as more sophisticated cost estimating relationships (CERs) based on regression analysis. For Monte Carlo simulation, probability distributions need to be estimated or selected for each variable.

In terms of presenting results to senior decision makers, we highly recommend the use of a standard format which includes use of a three-point scale to convey the idea that a cost estimate is not a single number but rather a continuum or distribution of values. Assumptions or scenarios associated with low, baseline, and high estimates should be stated to enable decision makers to see clearly the cost implications of events that can influence the outcome of an acquisition programme.

11.6 GUIDELINE FOR MULTI-NATIONAL PROGRAMMES

The life cycle cost studies for multi-national programmes follow the same principles as defined for national programmes. Nevertheless, there are some specifics that should be taken into account in terms of organisation, types of life cycle cost studies, cost models and presentation of results.

In terms of organisation, life cycle cost studies should be co-ordinated centrally by the pilot nation or the IPO or the NATO agency following the multi-national structure adopted. One or more participant(s) could perform a peer review including a verification and validation of the life cycle cost studies performed above.

The type of life cycle cost studies could be focused on the assessment of different alternatives related to commonality part. For this purpose, a specific process is necessary to identify the areas in which

alternatives could be defined and assessed. Figure 2-16 shows a process for the selection of the areas and the definition of the related scenario.

The basic principle for these studies is that they should be based on an agreed common life cycle cost framework. This implies the selection of a common model(s), the building of a common cost breakdown structure, the aggregation of the different outputs from the models, the definition of harmonised assumptions (in particular for deployment(s)) and a common process for data collection.

The life cycle cost results should be presented in one currency. The choice of the currency should be made before the launch of the life cycle cost studies and the evolution of the exchange rates taken into account in the model.

11.7 AWARENESS OF NEW DEVELOPMENTS IN METHODS AND MODELS

This study identified that the topic of joint war-fighting is becoming more important to NATO and this will influence the life cycle costing requirements. At present, there is insufficient information on how to evaluate the situation where a number of discrete assets share the information/data to provide a total capability solution. The costing of the assets themselves is straightforward, but when combined the interpretation on apportionment where multi-mission systems feed into several capabilities is not clear.

Viewing capabilities across the entire portfolio of assets enables decision makers to make better informed choices about how to reallocate resources with the ultimate goal of delivering needed capabilities to the joint force more rapidly and efficiently. Capability portfolios are intended to serve as a basis for strategic level trades by senior decision makers and it is essential the life cycle costing plays a major role in supporting this new development.

For the NATO and PfP cost community, this will cause a shift in emphasis from the analysis of individual programmes at key gates or milestones to the analysis of entire portfolios of assets. This will require further investigation and examination to assess the impact.

11.8 REVIEW AND POSSIBLE ENHANCEMENT OF NATO GENERIC COST BREAKDOWN STRUCTURE

The SAS-028 Task Group related to cost structures and life cycle costs for military systems developed a NATO generic cost breakdown structure and associated definitions that can be used by any military programme to construct its own cost breakdown structure. The outputs of this Task Group have been applied on specific programmes and some areas of enhancement have been suggested.

Chapter 12 – RECOMMENDATIONS

12.1 KEY RECOMMENDATIONS

The following key recommendations are made with regard to the development and improvement in life cycle costing for multi-national programmes.

12.1.1 Life Cycle Costing Methods

1) Life cycle cost estimates should be fully documented (Sub-section 2.3.2)

- A cost analyst should be able to re-create the complete estimate working from the documentation alone.
- All assumptions and data related to the study should be captured in an MDAL or CARD or similar document.
- Assumptions recorded in an assumptions list such as the MDAL or CARD should be questioned by an independent technical team.

2) All life cycle cost estimates should be prepared by suitably experienced personnel (Sub-section 5.2.3.1)

- Decisions such as budget setting and options analysis studies are often conducted when data to support cost forecasting and life cycle costing is very sparse. It is therefore essential that experienced personnel are used to conduct the life cycle cost estimates to support the decision process at these key stages.

3) The life cycle cost analysis should include an affordability analysis (Sub-section 2.9)

- Affordability plays an important part in programme decisions throughout the life cycle. Even before a programme is formally approved for initiation, affordability plays a key role in the identification of capability needs. This aspect is part of the process which balances cost versus performance and in establishing key performance parameters. Although this is not common practice in all nations the assessment of affordability is one that we recommend should be conducted by all nations.

4) Life cycle cost estimates, where possible, should use two independent methods for each cost breakdown structure element (Sub-section 4.4)

- The use of two independent methods to develop the life cycle cost estimates will improve the confidence in the results and help to validate the outputs. It is accepted that this may be tempered by the constraints imposed by a financial threshold (see Sub-section 2.6) or by a simple consideration of what the estimate will be used for (e.g., rough cost for initial views or detailed costs for decision making).

12.1.2 Life Cycle Cost Models

5) All life cycle cost models should be validated (Sub-section 5.5)

- It is essential that all life cycle cost models implemented through spreadsheets or more advanced programming techniques be validated by using recognised testing processes. This will increase confidence that the model is fit for purpose and that the input data and results can be assessed through a clear audit trail and mathematical reasoning of any cost estimating relationships.

12.1.3 Data for Life Cycle Costing

6) Investments should be made to increase the accuracy, visibility, and availability of cost, programmatic, technical, and performance data within the NATO/PfP cost analysis community (Chapter 6).

- Data collection forms a large part of the life cycle costing activity and significant effort is expended to gather and analyse the data so that it is suitable for use in life cycle cost analysis studies. Improvements in data exchange standards or even the development of a NATO costing database would:
  - Improve the quality of the life cycle cost estimate;
  - Reduce the effort needed to conduct the life cycle cost estimate; and
  - Reduce the time schedule to conduct the life cycle cost estimate.

12.1.4 Multi-National Programmes

7) For multi-national programmes the participating nations should agree on a common LCC framework (Sub-section 2.10.6)

- The life cycle cost studies for multi-national programmes follow the same principles as those required by a national study. However, there are some specifics that must be taken into account in terms of organisation, models and the presentation of results. It is essential that all parties in a multi-national programme agree on a common life cycle cost framework. This framework is determined by the costing boundary and the tools that will be employed to populate the framework. A common framework will provide consistency, comprehensiveness, traceability and audit. All are essential to achieve life cycle cost estimates in a timely and responsive manner.

12.1.5 NATO Generic Cost Breakdown Structure

8) Enhancements to the GCBS (generic cost breakdown structure) to improve its use (Chapter 10)

- It has been found that most nations have not adopted the generic cost breakdown structure reported in RTO-TR-058 as their national life cycle cost breakdown structure. However, the NATO generic cost breakdown structure has been applied on specific multi-national programmes and some areas of enhancement are recommended.

  The current structure does not allow the identification of the life cycle cost results over the time phasing for national financial and programme contributions. Therefore, it is recommended to include two dimensions in addition to the Activity, Product and Resource dimensions. These additional dimensions are:

  - Time phasing; and
  - National contribution.

  As the coding of the Generic Cost Breakdown is complex for non-experts, it is recommended to adopt a Generic Hierarchy for the GCBS.

12.1.6 Uncertainty and Risk

9) Risk and uncertainty analysis should be conducted at the same time as the life cycle cost estimate (Sub-section 7.9)

- Life cycle cost estimates of weapon system acquisition programmes are inherently uncertain and risky. To better support senior leadership, some sense of risk and uncertainty needs to be presented

at the same time as developing the point estimate. This will present the decision maker with a comprehensive true view of the programme's likely eventual outcome.

10) **The results of a life cycle cost estimate should be shown as a three point range of estimates (Sub-section 7.9)**

- A life cycle cost estimate is not a single number but rather a continuum or distribution of possible values.

12.2 FURTHER RECOMMENDATIONS

In addition to the key recommendations listed above it is further suggested that the other recommendations listed below are considered as each will help in the development and improvement in process and application of life cycle costing.

- We recommend that each nation sets its own financial threshold value for conducting life cycle cost studies and that this threshold should be determined in terms of total programme cost, political requirements and timeliness (Sub-section 2.6).
- To fully support the tender evaluation process, it is recommended that a life cycle cost questionnaire is issued with the tender documents so that the procurement agency can conduct an independent comparative life cycle cost evaluation on all the tenders. This will improve the understanding of the tender offer and provide a degree of credibility in the predicted life cycle costs results (Sub-section 2.8.3).
- We recommend that when supporting contractor submissions then all cost data and substantiating information is provided in a format that is clear, complete and ready for evaluation (Sub-section 2.8.3).
- There is a clear need for all participating nations in a multi-national acquisition to understand and trust the cost models used. The participating nations will need to agree on a common life cycle costing framework (as detailed in the key recommendations). It is further recommended that clear guidelines are produced with regard to which data to use and how to collect this data (Sub-section 2.10).
- The issue of a reference currency and currency exchange should be resolved prior to commencing any life cycle cost study. It is recommended that advice be sought from the recognised national economic advisor to ensure consistency and correctness in the application of the life cycle cost modelling (Sub-section 2.10.7).
- It is also recommended that each nation within a multi-national programme apply their own cost model and applicable data (CERs, labour rates, etc.) to arrive at its national cost estimate and that this information is used in the collective multi-national life cycle cost framework (Sub-section 2.10.7).
- Prior to the start of production it is recommended that a joint (contractor and government) risk register is developed to support the assessment of the financial risk liability and to assist in the risk management and mitigation activities (Sub-section 3.7.6.1).
- During and Post Manufacture, it is recommended that all actual costs incurred by the contractor are certified. This data can subsequently be used to refine and calibrate future cost forecasting models (Sub-section 3.7.6.3).
- It is recommended that research is conducted continuously to enhance methods and models for life cycle costing (Sub-section 4.4).
- It is recommended that anticipation is made of future data requirements to support life cycle costing and that the data is collected accordingly (Sub-section 6.1). To achieve this, an agreement

on well-documented templates or standards for the data to be exchanged should be reached between all the stakeholders (Sub-section 6.4).

- In individual nations, the regulations relating to the interpretation and calculation of tax may be different. Should this be a requirement for life cycle costing then it is recommended that advice should be sought with the appropriate national authorities (Sub-section 8.1).
- Larger (more expensive) programmes will usually demand more effort and rigor. It is recommended that sufficient time and effort should be allowed in order to provide a robust cost estimate to meet the programme requirements. However, there should be a balance between estimating effort and the value of the programme (Sub-section 2.6).
- A uniform communications format should be used for presenting the life cycle cost estimates risk analysis. This will aid the decision makers in their evaluation of programmes by presenting the basis of the spread of the costs, the method employed to conduct the simulation and the provision of the underlying assumptions (Sub-section 7.8).

12.3 FOLLOW-ON ACTIVITIES

The following paragraphs outline recommendations for further studies that would benefit the understanding and use of life cycle costing in NATO and multi-national environments.

- The next logical step on completion of SAS-054 would be to demonstrate the proof of concept (methods and models) described in the report by using a practical application of the guideline:
  - A typical example could be an existing NATO programme (but only using data that was available at the time) and/or any other multi-national programme (e.g. AWACS, AGS, JSF, NH-90, FREMM).
- Further research should be conducted in the area of capability portfolio analysis (see Chapter 9). This topic of joint warfare is becoming more important to NATO and, at present, there is insufficient information on how to evaluate the situation where a number of discrete assets share the information/data to provide a total capability solution.
  - An investigation into new methods and databases would support this requirement.
- Research into the life cycle costs of software. This report has not addressed software cost estimating as it was felt that this was a subject in its own right. Many academic studies are being conducted into open system architecture, modular construction and system behaviours that employ software intensive configurations.
  - Much is known about modern techniques in software development but the issue of assessing software quality, reliability and support costs is still vague.
- Life cycle cost estimates are produced for a variety of reasons. It would benefit the NATO community to investigate how the cost estimates are being used in the decision making process.
  - This could avoid the situation where enormous effort may be spent in generating cost estimates when the answer could have been given in a more simplistic and effective manner.
- Estimating accuracy has been an issue for many years. An evaluation could be conducted that studied the delta between the original cost estimates and the actual costs.
  - This would provide a benefit by having a definitive document that could provide a view of estimating accuracy across a number of procurement processes.

- Research should be conducted continuously to enhance methods and models for life cycle costing.
  - Periodically, the US Department of Defense undertake an initiative to review the basis and techniques employed in cost estimating. This is supported by industry, a number of academic groups and learned societies. However, these initiatives purely examine techniques that will be employed within the US. It would be beneficial to conduct a similar continual review across NATO and PfP nations.

- The SAS-054 study gathered information on each nation's approach and use of models to generate life cycle costs. The study did not get a clear comprehension on the range of the functionality that could be provided by some of these models.
  - It would be of benefit to look in more detail on how these life cycle costing models generate cost for Research and Development, Production, Operating and Support.

- The issue of calibration, verification and validation of cost estimating models is of paramount importance. However, little or limited space is given in handbooks on the requirements and methods of validating cost models.
  - A study could be initiated to develop a common methodology for validating cost models, this would help to ensure cost estimating consistency across NATO and PfP nations on each nation's approach and use of models to generate life cycle costs.

- All life cycle cost estimates are only as good as the data that underpins the estimate. Much investment has been made in adopting ERP-systems to support financial and project reporting. The use of these systems in providing good quality data to support life cycle cost estimating is not clearly known.
  - A study should be conducted to evaluate the benefits or otherwise in adopting an ERP-system versus the investment in a bespoke system (e.g. VAMOSC) to assist the life cycle cost data collection process and improve cost estimating methods and accuracy.

Annex A – NATION'S COMPLETED MATRIX

ISSUE 01	PHASES in LIFE CYCLE							
Date 15 12 2004	1	2	3	4	5	6	7	8
NATO LCC Phases	Mission need evaluation phase	Pre-feasibility phase	Feasibility phase	Project definition phase	Design and Development phase	Production phase	In-service phase	Disposal phase
	Acquisition phase							
National LCC Phases Nation: Denmark	Requirements statement (Basic Military Requirements, Operational User Requirements)				Acquisition (Market exploration, Invite tender, Tender evaluation, Type selection, Order)		Phase in + Service and maintenance phase	Phase out
Type of costing studies required					LCC-analysis to compare alternatives and establish budgets		Follow-up on LCC-analysis to validate budgets and validate and improve estimating techniques	
Description of the process or national guideline to be followed - how are we going to do this ?					Guideline/standard process is being developed			
What methods are used ?					Parametric			
What models are available ? Commercial models								
What models are available ? In house developed models					Standard generic Excel based model (Under development), Various purpose-made Excel models			
Requirements to apply national guideline	none	none	none	none	MOD requirement to develop and use guideline/standard process			none
Requirements to apply methods	none	none	none	none	none		none	none
Requirements to apply models	none	none	none	none	MOD requirement to develop and use generic framework model		none	none
Restrictions on applicable methods or models depending on the goal					Lack of expertise and experience. Low priority within MOD and Defence organisations.			
How can data be collected					DeMars SAP R/3 ERP system (Service data for similar systems)		DeMars SAP R/3 ERP system (Service data)	
How is risk and uncertainty considered ?	Expert opinion (very limited use)	Expert opinion (very limited use)	Expert opinion (very limited use)	Expert opinion (very limited use)	Expert opinion (very limited use), Sensitivity analysis		Expert opinion (very limited use)	Expert opinion (very limited use)
What models and tools are available to assess uncertainty ?					Simple Monte Carlo functionality implemented in generic model			
What models and tools are available for risk analysis?	none	none	none	none	none	none	none	none
Requirements to apply risk methodology	No	No	No	No	No	No	No	No

Abbreviations
CBA = Cost Benefit Analysis CBS = Cost Breakdown Structure COO = Cost of Ownership EVM = Earned Value Management IA = Investment Appraisal RFI = Request for Information RFQ = Request for Quotation SME = Subject Matter Expert UPC= Unit Production Cost

Commercial Models	"In-House" model Model	Methodology
	Generic Excel framework model (under development)	High level CBS, Parametric

Figure A-1: Completed Matrix from Denmark.

Issue	PHASES in LIFE CYCLE							
Date	1	2	3	4	5	6	7	8
NATO LCC Phases	Mission need evaluation phase	Pre-feasibility phase	Feasibility phase	Project definition phase	Design and Development phase	Production phase	In-service phase	Disposal phase
National LCC Phases Nation xxxxxxxx	préparation		conception		Réalisation		Utilisation	Démantèlement
Type of costing studies required	choice of operational solution Budget previsions		choice of technical solution definition of the full system, including ILS		Budget planning			
Description of the process to be followed - how are we going to do this ?	1st LCC estimation by end of phase		enhanced LCC estimation in end of phase file					
What tools are available ? Commercial Tools	FACET			PRICE, COST+				
What tools are available ? IN House Tools		MOPSOS (armored vehicule); SCOPE (ships) Excel based applications						
What methodologies are available ?	Analogy, CERs			Engineering				
Requirements to apply models/methodology	mandatory at end of phase		mandatory, whole along the phase		desirable		desirable	
Requirements to apply tools	none							
Requirements to apply methodology	none							
Restrictions on applicable methods depending on the goal								
How can data be collected		SIPROG : compiles all DGA contracts						
How is risk and uncertainty measured ?								
What models and tools are available to assess uncertainty ?								
What models and tools are available for risk analysis?								
Requirement to apply risk methodology								

Figure A-2: Completed Matrix from France.

ISSUE 01 Date 22 12 2004	PHASES in LIFE CYCLE							
	1	2	3	4	5	6	7	8
NATO LCC Phases	Mission need evaluation phase	Pre-feasibility phase	Feasibility phase	Project definition phase	Design and Development phase	Production phase	In-service phase	Disposal phase
National LCC Phases Nation Germany	**Analysis Phase**			**Risk Reduction Phase**		**Introduction Phase**	**Service Use**	
alternative *	**Analysis Phase**			**Procurement Phase**			**Service Use**	
Type of costing studies required	LCC analysis to compare alternatives and options, CBA			LCC analysis to compare alternatives and options, CBA		LCC analysis to compare alternatives and options, CBA	CBA	
Description of the process to be followed - how are we going to do this ?	CPM: approval required to enter next phase			CPM: approval required to enter next phase		CPM: approval required to enter next phase		
What tools are available ? Commercial Tools	in process to start using FACET			ACES PRICE CostXpert (COCOMO II)		ACES PRICE CostXpert (COCOMO II)	ACES PRICE CostXpert (COCOMO II)	
What tools are available ? IN House Tools	SCOPE Excel-sheets			SCOPE Excel-sheets		SCOPE Excel-sheets	SCOPE Excel-sheets	
What methodologies are available ?	Expert opinion, Analogy, Parametric, Engineering			Expert opinion, Analogy, Parametric, Engineering		Expert opinion, Analogy, Parametric, Engineering	Expert opinion, Analogy, Parametric, Engineering, Simulation	
Requirements to apply models/methodology	mandatory			mandatory		mandatory	mandatory	
Requirements to apply tools	none			none		none	none	
Requirements to apply methodology	none			none		none	none	
Restrictions on applicable methods depending on the goal	Availability of data, personnel, time and budget			Availability of data, personnel, time and budget		Availability of data, personnel, time and budget	Availability of data, personnel, time and budget	
How can data be collected	Manually, Information systems (limited), Answers to questionnaires			Manually, Information systems (limited), Answers to questionnaires		Manually, Information systems (limited), Answers to questionnaires	Manually, Information systems (limited), Answers to questionnaires	
How is risk and uncertainty measured ?	Expert opinion (IAGFA)			Sensitivity Analysis		Sensitivity Analysis	Sensitivity Analysis	
What models and tools are available to assess uncertainty ?	none			Risk Analysis of parametric models		Risk Analysis of parametric models	Risk Analysis of parametric models	
What models and tools are available for risk analysis?	Cost Estimation, WU AZF-Plan / Milestones VOCON / Reviews			Demonstrators, Simulations; Cost Estimation, WU AZF-Plan / Milestones		Cost Estimation, WU AZF-Plan / Milestones VOCON / Reviews	Cost Estimation, WU AZF-Plan / Milestones VOCON / Reviews	
Requirements to apply risk methodology	mandatory as part of CPM			mandatory as part of CPM		mandatory as part of CPM	mandatory as part of CPM	

Abbreviations
AZF-Plan= Arbeits-/ Zeit-/Finanzplan (Work, Time, Financial Plan)
CBA= Cost Benefit Analysis
CBS= Cost Breakdown Structure
CPM= Customer Product Management
IAGFA= Integr. Arbeitsgr. Fähigkeitsanalysen (Integrated Working Team Ability Analysis)
VOCON= Vorhabens Controlling (Integrated Controlling System)
WU= Wirtschaftlichkeitsuntersuchung (Value Research)

Commercial Models	**"In-House" model** Model	Methodology
ACES = Advanced Cost Estimating Systems	SCOPE = Cost Estimating Tool for Ships	
COCOMO II = Software Estimating Tool		
CostXpert = Software Cost Estimating Tool		
PRICE = Parametric Review of Information for Costing and Evaluation		
FACET = Family of Advanced Cost Estimating Tools		

* If you have products available that don´t need any modifications it is possible to reduce the Life Cycle of three phases (s. above)

Figure A-3: Completed Matrix from Germany.

ISSUE 01 Date 13 Dec 2004	PHASES in LIFE CYCLE 1	2	3	4	5	6	7	8
NATO LCC Phases	Mission need evaluation phase	Pre-feasibility phase	Feasibility phase	Project definition phase	Design and Development phase	Production phase	In-service phase	Disposal phase
National LCC Phases Nation GR/HAGS	Pre-Concept		**C**oncept	**A**ssessment	**D**emonstration	**M**anufacture	**I**n-service	**D**isposal
Type of costing studies required	CBA ,CBS							
Description of the process to be followed - how are we going to do this ?	Operational Analysis Studies							
What tools are available ? Commercial Tools	RFI							
What tools are available ? IN House Tools	CBS Formulas							
What methodologies are available ?	Expert Analysis							
Requirements to apply models/methodology	IBD							
Requirements to apply tools	IBD							
Requirements to apply methodology	Expert Analysis							
Restrictions on applicable methods depending on the goal	User Requirements							
How can data be collected	Manually							
How is risk and uncertainty measured ?	Expert Analysis							
What models and tools are available to assess uncertainty ?	RFI							
What models and tools are available for risk analysis?	RFI							
Requirements to apply risk methodology								

Abbreviations
CBA = Cost Benefit Analysis CBS = Cost Breakdown Structure RFI = Request for Information IBD- IS TO BE DEFINED

Commercial Models	**"In House" Models** Model	Methodology

Figure A-4: Completed Matrix from Greece.

Issue	PHASES in LIFE CYCLE							
Date	1	2	3	4	5	6	7	8
NATO LCC Phases	Mission need evaluation	Pre-feasibility phase	Feasibility phase	Project definition phase	Design and Development phase	Production phase	In-service phase	Disposal phase
National LCC Phases Nation ITALY	Italian Army uses the NATO Life Cycle phases							
Type of costing studies required	Overall constraints of costs and industrial capacity	Estimates of costs for prototypes and initial production, target unit production costs, life cycle costs, impact of inflation, budget changes, exchange rates		Update prior estimates as appropriate				Specific costing studies (according to the nature of systems concerned)
Description of the process or national guideline to be followed - how are we going to do this ?	Not applicable	RFP or equivalent, as applicable						
What methods are used ?	Analogy or parametric methodologies							
What models are available ? Commercial models	No specific commercial model							
What models are available ? In house developed models	Excel-based models and/or proprietary algorithms							
Requirements to apply national guideline	Some cost formats are mandated by the Government							
Requirements to apply methods	Some cost formats are mandated by the Government							
Requirements to apply models	Some cost formats are mandated by the Government							
Restrictions on applicable methods or models depending on the goal	No particular restriction for methods/models							
How can data be collected	Data collection is usually not automated							
How is risk and uncertainty considered ?	No standard exists for risk and uncertainty evaluation							
What models and tools are available to assess uncertainty ?	None							
What models and tools are available for risk analysis?	None							
Requirement to apply risk methodology	None							

Figure A-5: Completed Matrix from Italy.

ANNEX A – NATION'S COMPLETED MATRIX

Issue	PHASES in LIFE CYCLE							
Date 2006-09-10	1	2	3	4	5	6	7	8
NATO LCC Phases	Mission need evaluation	Pre-feasibility phase	Feasibility phase	Project definition phase	Design and Development phase	Production phase	In-service phase	Disposal phase
National LCC Phases Nation Norway	**Consept**		**Definition**		**Development**	**Aquisition**	**In-service**	**Disposal**
Type of costing studies required	CBA, WLC		CBA,WLC		CBA,WLC	CBA,WLC	CBA,WLC	CBA
Description of the process or national guideline to be followed - how are we going to do this ?	Operational Analysis Studies Mandatory		Feasibility studies Mandatory RFI		Feasibility studies Mandatory RFQ	Feasibility studies, follow-up Mandatory RFQ	Operational studies Mandatory	Feasibility studies Mandatory
What methods are used ?	Analogies, Parametric, Expert opinion		Activity Based Costing					
What models are available ? Commercial models	No model available or required				OPUS			
What models are available ? In house developed models	KOSTMOD, LCC-Analyzer, XI-based LCC single purpose models		KOSTMOD, LCC-Analyzer, XI-based LCC single purpose models, FLYT2				KOSTMOD, LCC-Analyzer	LCC-Analyzer,
Requirements to apply national guideline	National guideline exist for investments larger than 500 mill NOK (app 62 mill EUR)				Significant divagation from decision basis needs to be approved		No guideline on use of LCC	
Requirements to apply methods	Cost Benefit Analysis (incl LCC) on defined conseptual alternatives mandatory to all investments with LCC larger than 500 mill NOK (app 62 mill EUR)		Cost Benefit Analysis (incl LCC) on defined alternatives within the decided consept is mandatory to all investments with LCC larger than 500 mill NOK (app 62 mill EUR)		Significant divagation from decision basis needs to be approved			
Requirements to apply models	No specific model requirements, but use of models are mandatory							Desirable
Restrictions on applicable methods or models depending on the goal	Data availability, knowledge, personnel, budget and time available							
How can data be collected	Manually		Manually		Manually	Manually	Manually and information systems	Manually
How is risk and uncertainty considered ?	Probability of project accomplishment. Sensitivity analysis, expert opinion and experience on cost drivers, evaluation of risk and reliablity of input data based on alternative data sources and internal models i.e. related to logistics and availability rates. Risk should be evaluated both in terms of: 1) risk in data input and modelling and, 2) risk in defined requirements for future capability (i.e. number of aircraft, new tehnology etc)				Continuous risk evaluation in project using tools such as easy risk manager or similar.			
What models and tools are available to assess uncertainty ? What models and tools are available for risk analysis?	Easy Risk Manager, Extend, win RAMA, Orbit RCM, OPUS, @RISK, Crystal Ball, CARA fault tree, Access based FMECA tool							
Requirement to apply risk methodology	Mandatory							

Abbreviations	**Commercial Models**	**"In House" Models**	Methodology
CBA = Cost Benefit Analysis CBS = Cost Breakdown Structure COO = Cost of Ownership EVM = Earned Value Management IA = Investment Appraisal RFI = Request for Information RFQ = Request for Quotation SME = Subject Matter Expert UPC= Unit Production Cost	@Risk = Risk analysis tool Crystal Ball = Risk analysis tool OPUS = Modelling and spares optimisation Extend winRAMA Orbit RCM CARA fault tree	Easy Risk Manager Access based FMECA tool LCC Analyzer ILSR data base KOSTMOD = Force Structure Cost M FLYT2 = Air Force model, availability of aircraft and pilots	Parametric Activity based costing Weighted marking scheme Comparative/Parametric Risk based Parametric LCC Database

Figure A-6: Completed Matrix from Norway.

Issue	PHASES in LIFE CYCLE							
Date 2006-04-20	1	2	3	4	5	6	7	8
NATO LCC Phases	Mission need evaluation phase	Pre-feasibility phase	Feasibility phase	Project definition phase	Design and Development phase	Production phase	In-service phase	Disposal phase
National LCC Phases Nation Sweden	Concept developement phase		Concept evaluation phase	Definition and demonstration phase		Procurment phase	In-service phase	Disposal phase
Type of costing studies required	Costing for long term force structure planning.		CBA	CBA		CBA		
Description of the process or national guideline to be followed - how are we going to do this ?	Operational Analysis Studies, not mandatory		RFI, not mandatory	RFI, RFP, not mandatory The Act on Public Procurement is mandatory Gate: A number of different cost analyses has to be performed before a project is allowed to proceed to the Production phase, e.g. An estimate of Life Cycle Cost.		RFQ The Act on Public Procurement is mandatory Before a system is handed over to the Swedish Armed Forces from FMV an estimate of operating and maintenance costs shall be calculated by FMV. The estimate shall include scope, time plan for the outcome of costs divided on different resources and organisations and shall include cost for; operating and maintenance, consumtion of maintenance resources, operating and maintenance management, technical support, etc	RFQ The Act on Public Procurement is mandatory	RFQ The Act on Public Procurement is mandatory
What methods are used ?	CBS Parametric Analogy Expert opinion Rules of Thumb		CBS Parametric Analogy Expert opinion Sensitivity analysis to find cost drivers Normorganisation to define a baseline for the LCC-calculations Rules of Thumb Discrete Event Simulation	CBS Parametric Analogy Expert opinion Sensitivity analysis to find cost drivers Normorganisation to define a baseline for the LCC-calculations Rules of Thumb Discrete Event Simulation Optimisation		CBS Parametric Analytical Normorganisation to define a baseline for the LCC-calculations Discrete Event Simulation Optimisation		
What models are available ? Commercial models	CATLOC		CATLOC SIMLOX	CATLOC SIMLOX OPUS10				
What models are available ? In house developed models	CBS-model (including calculation formulas) Excelbased models		Various ILS systems, CBS-model (including calculation formulas) Excelbased models					
Requirements to apply national guideline	No national guidelines on the use of LCC for any phase The Act on Public Procurement is mandatory							
Requirements to apply methods	In larger projects the Armed Forces requires various maintenance analyses and CBS							
Requirements to apply models	Some models are recommended but none are required							
Restrictions on applicable methods or models depending on the goal	Data availability, knowledge, personnel, time, and budget							
How can data be collected	From Business Software Applications, ILS-systems, Industry, Manually, Interviews/Questionaires, Expert opinion							
How is risk and uncertainty considered ?	Sensitivity analysis, Expert opinion		Risk management plan, FMV working processes are linked to PMBOK Guide (A Guide to the Project Management Body of Knowledge) PMI - Project Management Institute. Sensitivity analysis, Expert opinion, Earned value management					
What models and tools are available to assess uncertainty ?	Spreadsheet models, templates and calculation formulas		Spreadsheet models, templates and calculation formulas based on working process and methodology from (A guide to the Management Body of Knowledge) PMI - Project Management Institute and internal working processes. Earned value management is recommended.					
What models and tools are available for risk analysis?	Spreadsheet models, templates and calculation formulas		Spreadsheet models, templates and calculation formulas based on working process and methodology from (A guide to the Management Body of Knowledge) PMI - Project Management Institute and internal working processes. Earned value management is recommended.					
Requirement to apply risk methodology			The Swedish Armed Forces requires the Swedish Defence Materiel Administration to perform project risk analysis, no specific models are required except working processes. FMV Risk management is linked to FMV working processes for project management which are linked to PMBOK Guide (A Guide to the Project Management Body of Knowledge) PMI - Project Management Institute. FMV working processes for Risk management is also linked to ISO 15288:5.4.6 Risk Management Process. Earned value management is recommended.					

Abbreviations	Commercial Models	In House Models			
		Model		Methodology	
RFI = Request for information RFQ = Request for Quotation RFP = Request for proposal CBA = Cost benefit analysis CBS = Cost Breakdown structure ILS = Integrated Logistic Support	CATLOC - system model for Life Cycle Cost (LCC) calculation and analysis OPUS - system model for modelling and optimization SIMLOX - discrete event Monte Carlo simulation model	ASTOR - Air Force Simulation of Tactics and Operational Resources			**The Act on Public Procurement** - Since FMV is engaged in public sector procurement, there are rules and regulations that have to be followed. The principal regulations are contained in **The Act on Public Procurement** which applies to all public sector organisations. The fundamental principle is that procurement should be conducted in a businesslike, competitive and objective way. The regulations also contain rules governing procurement procedures, tender enquiries, the security of classified information, tender opening, assessment of tenderers, tender evaluation and other matters that must be followed by the procuring authority. FMV must also check that a new contractor is registered for VAT and does not have any tax payments outstanding.

Figure A-7: Completed Matrix from Sweden.

Issue	PHASES in LIFE CYCLE							
Date	1	2	3	4	5	6	7	8
NATO LCC Phases	Mission need evaluation phase	Pre-feasibility phase	Feasibility phase	Project definition phase	Design and Development phase	Production phase	In-service phase	Disposal phase
National LCC Phases Nation: **Switzerland**	**Preconcept**		**Concept**	**Evaluation** Longlist, field evaluation, Shortlist		**Aquisition**	**In service**	**Disposal phase**
Type of costing studies required	Studies to Compare Strategic Alternatives, CBA		CBA	CBA / WLC		COO	Operational Studies Mandatory	Feasibility Studies Desirable
Description of the process or national guideline to be followed - how are we going to do this ?	Operational Analysis Mandatory		RFI Independent Estimate	Tender Assessment		Contract Data	Actual Costs	Independent Estimate
What methods are used ?	Analogy		CBS	CBS		CBS	CBS	Analogy
What models are available ? Commercial models	Excel Sheets		Ecel Sheets	Excel Sheets		Ecel Sheets	Ecel Sheets	Ecel Sheets
What models are available ? In house developed models	SAP Business Warehouse Excel Sheets		SAP Business Warehouse Excel Sheets	SAP Business Warehouse Excel Sheets		SAP Business Warehouse Excel Sheets	SAP Business Warehouse Excel Sheets	SAP Business Warehouse Excel Sheets
Requirements to apply national guideline	Desirable		Mandatory for Major Projects Desirable	Mandatory for Major Projects Desirable		Desirable	Desirable	Desirable
Requirements to apply methods	Desirable		Desirable	Desirable		Desirable	Desirable	Desirable
Requirements to apply models	Desirable		Desirable	Desirable		Desirable	Desirable	Desirable
Restrictions on applicable methods or models depending on the goal	Personal, Time, System & Budget Requirements		Personal, Time, System & Budget Requirements					
How can data be collected	Mandatory		Mandatory	Mandatory		Mandatory	Mandatory	Mandatory
How is risk and uncertainty considered ?	None		None	None		None	None	None
What models and tools are available to assess uncertainty ?	None		None	None		None	None	None
What models and tools are available for risk analysis?	None		None	None		None	None	None
Requirement to apply risk methodology				Mandatory				

Abbreviations	**Commercial Models**	**"In House" Models**	
		Model	Methodology
CBA = Cost Benefit Analysis		LCC Analyzer	Activity Based Costing
CBS = Cost Breakdown Structure			
COO = Cost of Ownership			
RFI = Request for Information			
WLC = Whole Life Cycle Cost			

Figure: A-8: Completed Matrix from Switzerland.

ISSUE 01 Date 13 Dec 2004	PHASES in LIFE CYCLE 1	2	3	4	5	6	7	8
NATO LCC Phases	Mission need evaluation phase	Pre-feasibility phase	Feasibility phase	Project definition phase	Design and Development phase	Production phase	In-service phase	Disposal phase
National LCC Phases Nation The Netherlands	**Pre-Phase A**	**Phase A: Statement of requirement**			**Phase B/C/D: (preliminary) study & preparation for procurement**	**Realisation**	**In-service**	**Disposal**
Type of costing studies required	High level studies to compare strategic alternatives	Determine costs of currrently used equipment that need to be replaced (to be used as a benchmark) Preparing questionnaires			LCC analysis to compare alternatives and options CBA and Business Cases Preparing questionnaires	LCC analysis to compare alternatives and options CBA and Business Cases Preparing questionnaires	LCC analysis to compare alternatives and options CBA and Business Cases Preparing questionnaires	Replacement studies, CBA
Description of the process or national guideline to be followed - how are we going to do this ?		DMP /RFI: approval required to enter next phase, FEL-SALDO step-by step approach for LCC-analysis			DMP / RFQ & RFP approval required to enter next phase FEL-SALDO step-by step approach for LCC-analysis	FEL-SALDO step-by step approach for LCC-analysis	DMP Phase E: evaluation of process followed (only large projects)	-
What methods are used ?	Analogy	Analogy, Parametric			Analogy, Engineering, Parametric, Expert opinion, Rule of Thumb	Analogy, Engineering, Parametric, Expert opinion, Rule of Thumb	Engineering	Rule of Thumb
What models are available ? Commercial models	none	none			none	none	none	none
What models are available ? In house developed models	LCC tool and Excel spreadsheet tools	LCC tool and Excel spreadsheet tools			LCC tool and Excel spreadsheet tools	LCC tool and Excel spreadsheet tools	LCC tool and Excel spreadsheet tools	LCC tool and Excel spreadsheet tools
Requirements to apply national guideline	DMP process is obliged	DMP process is obliged, FELSALDO CBS is obliged in DMP			DMP process is obliged, FELSALDO CBS is obliged in DMP	DMP process is obliged, FELSALDO CBS is obliged in DMP	DMIP is under development	
Requirements to apply methods	none	none			none	none	none	none
Requirements to apply models	none	none			none	none	none	none
Restrictions on applicable methods or models depending on the goal	Availability of data, personnel, time and budget	Availability of data, personnel, time and budget			Availability of data, personnel, time and budget	Availability of data, personnel, time and budget	Availability of data, personnel, time and budget	Availability of data, personnel, time and budget
How can data be collected	Manually, Information systems (limited), Answers to questionnaires	Manually, Information systems (limited), Answers to questionnaires			Manually, Information systems (limited), Answers to questionnaires	Manually, Information systems (limited), Answers to questionnaires	Manually, Information systems (limited), Answers to questionnaires	Manually, Information systems (limited), Answers to questionnaires
How is risk and uncertainty considered ?	sensitivity analysis, expert opinion	sensitivity analysis, expert opinion			sensitivity analysis, expert opinion	sensitivity analysis, expert opinion	sensitivity analysis, expert opinion	sensitivity analysis, expert opinion
What models and tools are available to assess uncertainty ?	New (in house developed) LCC tool covers uncertainty, Crystal Ball is also available	New (in house developed) LCC tool covers uncertainty, Crystal Ball is also available			New (in house developed) LCC tool covers uncertainty, Crystal Ball is also available	New (in house developed) LCC tool covers uncertainty, Crystal Ball is also available	New (in house developed) LCC tool covers uncertainty, Crystal Ball is also available	New (in house developed) LCC tool covers uncertainty, Crystal Ball is also available
What models and tools are available for risk analysis?	-	-			-	-	-	-
Requirement to apply risk methodology	mandatory as part of DMP	mandatory as part of DMP			mandatory as part of DMP	-	-	-

Abbreviations
LCC = Life Cycle Costs
CBS = Cost Breakdown Structure
CBA = Cost Benefit Analysis
FELSALDO = FEL Step by step Approach to Analyse Life cycle costs in the Defence Organisation
DMP = Defence Materiel Process
RFI = Request for Information
RFQ = Request for Quotation
RFP = Request for Proposal
DMIP = Defence Materiel In-service Process

Commercial Models	**"In House" Models** Model	Methodology
Crystal Ball	LCC tool	

Figure A-9: Completed Matrix from The Netherlands.

ISSUE 02	PHASES in LIFE CYCLE							
Date 10 04 2006	1	2	3	4	5	6	7	8
NATO LCC Phases	Mission need evaluation phase	Pre-feasibility phase	Feasibility phase	Project definition phase	Design and Development phase	Production phase	In-service phase	Disposal phase
National LCC Phases Nation TURKEY	**Pre-concept**		**Concept**	**Project Definition Phase**	**Engineering & Product Development**	**Manufacture**	**Operation & Maintenance**	**Disposal**
Type of costing studies required	CBA		CBA, UPC, WLC	UPC, WLC	UPC, WLC	UPC, WLC	WLC	WLC
Description of the process or national guideline to be followed - how are we going to do this ?	OR Studies, Construction of CBS		Elaboration of CBS, RFI, RFP	Tender Assessment, Scheduling	Verification of CBS, Tender Assessment	Verification of CBS, Scheduling	Verification of CBS, Deriving actual costs	
What methods are used ?	Analogy, Contingency Analysis, Pairwise Comparisons, Multi-objective Analyses		Parametric Comparisons, Regression Analysis	Parametric Analyses	Parametric Analyses, Discrete Event Simulation	Discrete Event Simulation	Activitiy Based Costing	Parametric comparisons
What models are available ? Commercial models	EXCEL, ExpertChoice, Theater Level Simulation Tools		EXCEL, MS Project Manager	EXCEL, MS Project Manager	EXCEL, ARENA	EXCEL, ARENA, MS Project Manager	EXCEL, ARENA	EXCEL, Expert Choice
What models are available ? In house developed models	BESTSEL, BAM		GVCAM, FMSCAM, ALCAM, BAM	ALCAM, P3M	CALS*	CALS*	CALS*, EDCAM, EXCAM	CALS*, BESTSEL
Requirements to apply national guideline	Desirable		Desirable	Mandated	Mandated	Mandated	Mandated	Desirable
Requirements to apply methods	Desirable		Desirable	Desirable	Desirable	Desirable	Some methods are mandated by the General Staff	Desirable
Requirements to apply models	Desirable		Desirable	Desirable	Desirable	Desirable	Some models are mandated by the General Staff	Desirable
Restrictions on applicable methods depending on the goal	Personnel, time, system and budget requirements		Personnel, time, system and budget requirements					
How can data be collected	Manual Records, General Information & Data Systems		Manual Records, General Information & Data Systems	Manual Records, General Information & Data Systems	Manual Records, General Information & Data Systems	Manual Records, General Information & Data Systems	Manual Records, General Information & Data Systems	Manual Records, General Information & Data Systems
How is risk and uncertainty measured ?	Sensitivity Analysis		Sensitivity Analysis, Monte Carlo Simulation	Monte Carlo Simulation	Monte Carlo Simulation			
What models and tools are available to assess uncertainty ?								
What models and tools are available for risk analysis?	CALS*, RISKSIM, Statistical Software Packages		CALS*, RISKSIM, Statistical Software Packages	CALS*, RISKSIM, Statistical Software Packages	CALS*, RISKSIM, Statistical Software Packages			
Requirements to apply risk methodology	Access to SME							

Abbreviations	**Commercial Models**	**"In-House" Models**	**Methodology**
CBA = Cost Benefit Analysis	ARENA Standard Edition 8.0 (including OptQuest feature)	BESTSEL : Best Selection (Prioritization Tool Based on Optimization)	Sensitivity Analysis
CBS = Cost Breakdown Structure	Expert Choice (Advanced Desicion Support Software)	BAM : Budget Allocation Model	Contingency Analysis
RFI = Request for Information	Theater Level Simulation Tools : NIMROD, TAMARI	GVCAM : Ground Vehicle Cost Analysis Model	Heuristics
RFQ = Request for Quotation	Statistical Software Packages : JMP, SPSS, Bestfit	ALCAM : Aircraft Life Cycle Cost Analysis Model	Scheduling Theory
SME = Subject Matter Expert	Optimization Tools : Lingo 8.0 Extended Optimizasyon Paketi	FMSCAM : Foreign Military Students Cost Analysis Model	Regression Analysis
UPC= Unit Production Cost	Extended What's Best 7.0	P3M : Pre-payment for Projects Model	Activity Based Costing
WLC= Whole Life Cost	Extended Large-Scale LP	EDCAM : Educational Cost Effectiveness Analysis Model	
	Solver Engine V5.5E	EXCAM : Exercises Cost Effectiveness Analysis Model	
	Premium Solver Platform for Excel V5.5	CALS - ILS : Continuous Acquisition Lifetime Support - Integrated Logistic Support Module	
		General Information & Data Systems : Air Forces Information System, Logistics Information System, C2 Information System	

Figure A-10: Completed Matrix from Turkey.

ISSUE 02	PHASES in LIFE CYCLE							
Date 5 Apr 2006	1	2	3	4	5	6	7	8
NATO LCC Phases	Mission need evaluation phase	Pre-feasibility phase	Feasibility phase	Project definition phase	Design and Development phase	Production phase	In-service phase	Disposal phase
National LCC Phases Nation: U.S. Dept. of Defense DoD Instruction 5000.2, Issued May 2003	Pre System Acquisition				System Acquisition		Sustainment	
	Concept Refinement		Technology Development		System Develop. & Demonstration	Production & Deployment	Operations & Support	Included in O&S
		Milestone A ^		Milestone B ^	Milestone C ^	Possible additional milestones for major updates		
Type of costing studies required	"Rough cost assessment" as part of JCIDS analysis; AoAs		At milestone B and C: AF; APB; CARD for MDAPs & MAIS; cost assessment (for certain ACAT levels); LCCE; EA & CCA for MAISs; ICE for MDAPs; PBL EA			ICEs for FRP DRs (in production phase); also, updates of prior cost estimates for new increments		
Description of the process or national guideline to be followed -	The U.S. DoD cost analysis community follows policies and procedures as promulgated in DoD Instruction 5000.2, "Operation of the Defense Acquisition System," and in all implementing guidance to this instruction.							
What methods are used ?	Rough analogies; high-level parametric cost estimating relationships (CERs)		Analogy & Parametric		Analogy, parametric & engineering build up	Parametric & engineering build up	Parametric	Analogy & Parametric
What models are available ? Commercial models What models are available ? In house developed models	Literally hundreds of models are available. Each DoD component involved in cost estimating buys and develops tools and models appropriate to the types of systems relevant to that organization. MS Excel is the DoD standard spreadsheet. For MDAPs and MAISs, OSD and each Service typically develop a cost-estimating model unique to that system.							
Requirements to apply national guideline Requirements to apply methods Requirements to apply models Restrictions on applicable methods or models depending on the goal	DoD and Service-level guidance specify, in detail, what cost-analysis products are required at various milestones in the acquisition process. However, considerable latitude is permitted in terms of *how* to actually produce the deliverables. The individual analyst has great intellectual freedom in generating a cost estimate.							
How can data be collected	Cost data are available through the DoD and Service budgeting and accounting systems; formal reports such as CCDRs, SRDRs, CPRs, SARs, DAES reports; internal contractor accounting data; and through numerous cost/technical database efforts throughout the cost community.						VAMOSC	VAMOSC
How is risk and uncertainty considered ?	Varies within and between cost-estimating organizations. A detailed study is available.							
What models and tools are available to assess uncertainty ?	Varies by cost-estimating organization. A detailed study is available.							
What models and tools are available for risk analysis?	Commercial tools such as Crystal Ball and @Risk are widely available in DoD but not used consistently.							
Requirement to apply risk methodology	Varies by cost-estimating organization. A detailed study is available.							

List of abbreviations	
ACAT	Acquisition Category
AF	Affordability Assessment
AoA	Analysis of Alternatives
APB	Acquisition Program Baseline (contains cost goals, in addition to performance and schedule goals)
CARD	Cost Analysis Requirements Description
CCA	Component Cost Analysis
CCDR	Contractor Cost Data Report
CER	Cost Estimating Relationship
CPR	Contract Performance Report
DAES	Defense Acquisition Executive Summary report
DoD	Department of Defense
EA	Economic Analysis
FRP DR	Full-rate Production Decision Review
ICE	Independent Cost Estimate
JCIDS	Joint Capabilities Integration and Development System (CJCSI 3170.01E; 11 May 2005)
LCCE	Life Cycle Cost Estimate
MAIS	Major Automated Information System
MDAP	Major Defense Acquisition Program
PBL	Performance Based Logistics
SAR	Selected Acquisition Report
SRDR	Software Resources Data Report
VAMOSC	Visibility and Management of Operating and Support Costs

Figure A-11: Completed Matrix from the United States of America.

ISSUE 03 Date 04 April 2006	PHASES in LIFE CYCLE							
	1	2	3	4	5	6	7	8
NATO LCC Phases	Mission need evaluation phase	Pre-feasibility phase	Feasibility phase	Project definition phase	Design and Development phase	Production phase	In-service phase	Disposal phase
National LCC Phases Nation UK MOD CADMID	Pre-Concept		**C**oncept	**A**ssessment	**D**emonstration	**M**anufacture	**I**n-service	**D**isposal
Type of costing studies required	BoI, CBA	UPC, WLC, COO	UPC,IA, WLC, COO	UPC,IA, WLC, COO	UPC,WLC, COO	UPC, WLC, COO	IA, WLC, COO	WLC, COO
Description of the process or national guideline to be followed - how are we going to do this ?	Operational Analysis Studies	Bayesian, Parametric, Analogy	RFI, Independent estimate	RFQ, Independent estimate	Tender Assessment	Contract data	Actual Costs	Independent estimate
What methods are used ?	Saaty, Pair-Wise,	Bayesian, Parametric, CGT, Regression Analysis	CBS, CGT,Regession Analysis, COO	CBS, CGT,Regession Analysis, COO	CBS, CGT, MACE, COO	CBS, COO	CBS, COO	Analogy, COO
What models are available ? Commercial Models	Portfolio, Option Analyser	FACET, PRICE, SEER	FACET, PRICE, SEER, COCOMO	FACET, PRICE, SEER, COCOMO, OSCAM, ILS Tools	ILS Tools, OSCAM, COCOMO	Metify, OSCAM, OPUS	Metify, OSCAM, OPUS	Metify, OSCAM, Excel
What models are available ? In House Models	Operational Analysis Studies	EXCEL,SPRUCE, MELICCA, A-credit, OATS, SSCM	EXCEL,SPRUCE, MELICCA, A-credit, OATS & COO System, SSCM	EXCEL,SPRUCE, MELICCA, A-credit, OATS & COO System, SSCM	EXCEL,SPRUCE, MELICCA, A-credit, OATS & COO System, SSCM	Excel, OATS & COO System	Excel, OATS & COO System	Excel, OATS & COO System
Requirements to apply national guideline on LCC	Desirable	Desirable	Mandatory for major Projects / Desirable	Mandatory for major Projects / Desirable	Mandatory for major Projects / Desirable	Mandatory for major Projects / Desirable	Mandatory for major Projects / Desirable	Desirable
Requirements to apply methods	Desirable	Desirable	Desirable	Desirable	Desirable	Desirable	Desirable	Desirable
Requirements to apply models	Desirable	Desirable	Desirable	Desirable	Desirable	Desirable	Desirable	Desirable
Restrictions on applicable methods and/or models depending on the goal	Access to SME, User Requirements	Access to SME, User Requirement	Access to Data, System Requirement	Access to Data, Design Data	Access to Data, Design Data	Contract conditions restricting access to actuals, Design data	Contract conditions restricting access to actuals	Planning Assumptions
How can data be collected ?	Manually	Manually	Manually	Manually	Manually	Manually, EVM	Manually	Manually
How is risk and uncertainty measured ?	Sensitivity Analysis	Sensitivity Analysis	Detailed Modelling	Detailed Modelling	Risk Management & Analysis	Risk Management & Analysis	Risk Management & Analysis	Sensitivity Analysis
What models and tools are available to assess uncertainty ?	@RISK, Predict, Arrisca, Crystal Ball, Optimism Bias	@RISK, Predict, Arrisca, Crystal Ball, Optimism Bias	@RISK, Predict, Arrisca, Crystal Ball, Optimism Bias	@RISK, Predict, Arrisca, Crystal Ball	@RISK, Predict, Arrisca, Crystal Ball	@RISK, Predict, Arrisca, Crystal Ball	@RISK, Predict, Arrisca, Crystal Ball	@RISK, Predict, Arrisca, Crystal Ball
What models and tools are available for risk analysis ?	TDRM	TDRM	ARM, Arrisca, Predict Risk Controller, PERTMaster	ARM, Arrisca, Predict Risk Controller, PERTMaster	ARM, Arrisca, Predict Risk Controller, PERTMaster	ARM, Arrisca, Predict Risk Controller, PERTMaster	ARM, Arrisca, Predict Risk Controller, PERTMaster	TDRM, PERTMaster
Requirements to apply risk methodology		Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory

Abbreviations
CBA = Cost Benefit Analysis
CBS = Cost Breakdown Structure
COO = Cost of Ownership
BOI = Balance of Investment
EVM = Earned Value Management
IA = Investment Appraisal
RFI = Request for Information
RFQ = Request for Quotation
SME = Subject Matter Expert
UPC= Unit Production Cost

Commercial Models
@Risk = Risk analysis tool
A-Credit = Automated cost resource evaluation and data integration tool
ARM = Active Risk Manager
Arrisca = Risk Management and analysis tool (Cost & Schedule)
COCOMO = Software estimating tool
Crystal Ball = Risk analysis tool
FACET = Family of Cost Estimating Tools
Metify = Activity based costing/management (ABC/M)
OPUS = Modelling and spares optimisation
PERT Master = Schedule risk management and analysis tool
Predict Risk Controller = Schedule risk management and analysis tool
PRICE = Parametric cost estimating models
SEER Parametric cost estimating models
SSCM = Software Support Cost model
TDRM = Top Down Risk Model

"In House" Models Model	Methodology
CGT = Compensated Gross Tonnage (Ships)	Parametric
Force Structure Cost Model	Activity based costing
MACE = 'Multi(ple) Attribute Choice Elucidation' (Cost is just one element)	Weighted marking scheme
MACRO (Method for Assessing Cost of exploiting Research Output)	Comparative/Parametric
MELICCA = Cost collection tool	Activity based costing
SPRUCE= Ship Platform Risk based Unit Cost Estimates	Risk based Parametric
OATS & COO System = Options and Affordability Tools Set & Cost of Ownership System	Activity based costing

Figure A-12: Completed Matrix from the United Kingdom.

Annex B – EXAMPLES OF DATA FORMS FOR CAPTURING THE COSTS AT THE PRODUCTION PHASE

Sheet 1 of 2

Attachment to PFG/PR/ 208?

Appendix A

CONTRACTOR DATA PACK AVAILABILITY

Issue 1

Insert MoD Proposal Reference here please >>>

For information refer to; MOD Guidelines to Industry "Partnering between MOD and its Suppliers"

BELOW IS A LIST OF GENERIC ITEMS
TICK THE RELEVANT COLUMN TO INDICATE IF THE ITEM IS AVAILABLE TO SUPPORT YOUR QUOTATION

ITEMS	INCLUDED			IF YES - QUOTE REF. and ISSUE IF NO - please comment
Preferred, all items below on 3.5" disk(s), except items 9, 14 to 29. (MS Office Word 7.0a for Text Files, Excel 7.0a for Spreadsheets)	**Available on Disc?**	*Yes*	*NO*	
1 Work Breakdown Structure Details				
2 List of Work Packages				
3 Listing of Cost centres used by depart./Divisions/Sites involved				
4 Risk Analysis Documentation (e.g. Risk Register)				
5 Specify Reference and Issue for quotation				
(a) Build Standard				
(b) Technical Specification				
(c) Performance Specification				
(d) Specification of Requirements				
(e) Delivery Programme				
(f) Questionnaire on the Method of Allocation of Costs (QMAC) used as a base				
6 Development Cost Plan				
7 Production Cost Plan				
8 Unit Production Cost Estimates				
9 Parallel manuf. and Productivity Improvements/Efficiency Gains				
10 Payment Plan				
11 Estimating Rationale Statement				
12 List of estimating Allowances and Contingencies used, incl. Learner, escalation and contingency rationale				
13 Applied Estimating Assumptions				
14 Make/Buy Plan				
15 Material Estimates,				
(a) including rationale for going Competitive				
(b) rationale for Sub-contractor selection				

Continues on Sheet 2 >>

Figure B-1: UK Contractor Data Sheet – Appendix A.

Sheet 2 of 2 | Attachment to PFG/PR/ 2082

Appendix A

Issue 1

CONTRACTOR DATA PACK AVAILABILITY

Insert MoD Proposal Reference here please >>>

For information refer to; MOD Guidelines to Industry "Partnering between MOD and its Suppliers"

BELOW IS A LIST OF GENERIC ITEMS
TICK THE RELEVANT COLUMN TO INDICATE IF THE ITEM IS AVAILABLE TO SUPPORT YOUR QUOTATION

	ITEMS	Yes	NO	IF YES - QUOTE REF. and ISSUE / IF NO - please comment
16	List all Non-competitive Major Sub-contractors, (a) are supply copies of Quotations available			
17	List of all Proprietary Items and Basis of Pricing, linked to WPs.			
18	Labour Estimates			
19	Statement defining any New or innovative manuf. techniques			
20	List assumptions for all Government Funded Equipment (GFE)			
21	List proposed Tooling, including scale and scope			
22	Statement on the Economic Datum Point of Estimate/Quotation, ie. June 2001			
23	Inflation Factors used and Source, e.g. RPI, Indices etc..			
24	Labour and Material Spend Profile			
25	Recorded Costs (a) incurred against this Proposal, if converted to a contract			
	(b) Previous Contracts for Same Equipment			
	(c) Contracts of Similar Nature			
26	Details of the proposed Earned Value Management scheme (if applicable) and outputs from similar projects either completed or in progress.			
27	Direct Labour Rates Used and their Status. This should include the estimating assumptions regarding; (a) labour utilisation			
	(b) future work programme covering the duration of the subject contract			
	(c) department loadings			
	(d) estimated % of MoD/Commercial workload split for the duration of the subject contract			
28	Assumptions regarding incentivisation and or gainshare.			
29	A statement regarding any omissions from the proposal or non-compliance with the RFQ/ITT eg. a. cannot provide a firm price proposal			
	b. can only supply 75 instead of 100, in the delivery period requested.			

Figure B-1: UK Contractor Data Sheet – Appendix A (Continued).

Attachment to PFG/PR/ 2082

Appendix B

CONTRACTOR DATA PACK - SUPPORT CHECKLIST

Insert MOD Proposal Reference here please >>>

For information refer to; MOD Guidelines to Industry "Partnering between MOD and its Suppliers"

TICK THE RELEVANT COLUMN TO INDICATE THAT THE FOLLOWING ITEMS OR EQUIVALENT ARE AVAILABLE ON-SITE, ON REQUEST FOR MoD PFG

	ITEMS	AVAILABLE		IF YES - QUOTE REF. and ISSUE IF NO - please comment
		YES	*NO*	
1	Quotation Specifications and Plans			
	(i) Specification of Requirement linked to Task Booking Structure			
	(ii) Build Standard/Technical Specification			
	(iii) Performance Specification			
	(iv) Quality Plan			
	(v) Make/Buy Plan			
	(vi) Delivery Programme			
2	Process Layout			
3	Process Specifications			
4	Operation Schedules			
5	Statistics to support any applied Learner Allowance			
6	Route Cards			
7	Manufacturing Drawings			
8	Parts Lists			
9	Test Specifications/Schedules			
10	Process Drawings/Specifications			
11	Competitive material and sub-contract quotations/invoices			
12	Statement on Plant, Processes and Techniques to be employed.			
13	Overheads Rates			
	(i) Overheads Budgets/Forecasts			
	(ii) Forward Load in Hours/Manning Levels			
	(iii) Company Strategy and Rationalisation Plans			
	(iv) Pay Deals			
	(v) Productivity Deals			
14	Copy of Business Plan			
15	Cash Flow & Profit and Loss Predictions			
16	Supporting Data for Claimed Profit Rate, including CP:CE Claims			
17	Access to Company Estimating Request Forms (ERFs) from Departmental bid returns.			
18	Access to Company Estimating Database information and/or Computer Models where appropriate.			

Figure B-2: UK Contractor Data Sheet – Appendix B.

SECURITY CLASSIFICATION

FUNCTIONAL COST-HOUR AND PROGRESS CURVE REPORT

Form Approved
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 45 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions reducing the burden to Department of Defense, Washington Headquarters Service, Directorate for Information Operations and Reports (0704-0188), 1251 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THIS ADDRESS

1a. PROGRAM	1b. APPROVED PLAN NUMBER	2. REPORT AS OF *(MM/DD/YY)*	3. FY FUNDED

4a. CONTRACTOR TYPE
☐ PRIME/ASSOCIATE ☐ SUBCONTRACTOR ☐ SUBCONTRACT *(Estimate by Reporting Contractor)*

4 b. NAME/ADDRESS *(Include ZIP Code)*

5. DOLLARS IN

6. HOURS IN

7a. CUSTOMER *(Subcontractors Use Only)*

7b. SUBCONTRACTOR *(Estimated by Reporting Contractor)*

8. SUBCONTRACT NO.

9. NUMBER OF REPORTING SUBCONTRACTORS

10. TYPE ACTION
☐ CONTRACT NO. ________ LATEST AMENDMENT ________
☐ RFP NO. ________
☐ PROGRAM ESTIMATE

11. MULTI-YEAR CONTRACT
☐ YES ☐ NO

12. WBS ELEMENT CODE

13. REPORTING ELEMENT

PART I. FUNCTIONAL COST-HOUR REPORT

14. COST TYPE
☐ RECURRING
☐ NONRECURRING
☐ TOTAL

15. QUANTITY
TO DATE
AT COMPLETION

16. APPROPRIATION
☐ RDT&E
☐ PROCUREMENT

DATA ELEMENTS	**REPORTING CONTRACTOR** TO DATE A	AT COMPLETION B	**SUBCONTRACT OR OUTSIDE PRODUCTION AND SERVICES** TO DATE C	AT COMPLETION D	**TOTAL** TO DATE E	AT COMPLETION F
ENGINEERING						
1. DIRECT LABOR HOURS						
2. DIRECT LABOR DOLLARS						
3. OVERHEAD						
4. MATERIAL						
5. OTHER DIRECT CHARGES *(Specify)*						
6. TOTAL ENGINEERING DOLLARS						
TOOLING						
7. DIRECT LABOR HOURS						
8. DIRECT LABOR DOLLARS						
9. OVERHEAD						
10. MATERIAL AND PURCHASED TOOLS						
11. OTHER DIRECT CHARGES *(Specify)*						
12. TOTAL TOOLING DOLLARS						
QUALITY CONTROL						
13. DIRECT LABOR HOURS						
14. DIRECT LABOR DOLLARS						
15. OVERHEAD						
16. OTHER DIRECT CHARGES *(Specify)*						
17. TOTAL QUALITY CONTROL DOLLARS						
MANUFACTURING						
18. DIRECT LABOR HOURS						
19. DIRECT LABOR DOLLARS						
20. OVERHEAD						
21. MATERIALS AND PURCHASED PARTS						
22. OTHER DIRECT CHARGES *(Specify)*						
23. TOTAL MANUFACTURING DOLLARS						
OTHER COSTS						
24. PURCHASED EQUIPMENT						
25. MATERIAL OVERHEAD						
26. OTHER COSTS NOT SHOWN ELSEWHERE *(Specify)*						
SUMMARY						
27. TOTAL COST (Direct and Overhead)						

28. REMARKS

POINT OF CONTACT (POC) INFORMATION

29a. NAME *(Last, First, Middle Initial)*	29b. DEPARTMENT	29c. TELEPHONE NO. *(Include Area Code)*	
29d. E-MAIL ADDRESS	29e. FAX NO. *(Include Area Code)*	29f. SIGNATURE	29g. DATE SIGNED *(MM/DD/YY)*

DD FORM 1921-1, (FRONT), OCT 2003

SECURITY CLASSIFICATION

Figure B-3: USA Functional Cost Hour and Progress Curve Report (DD Form 1921-1 Front).

SECURITY CLASSIFICATION

FUNCTIONAL COST-HOUR AND PROGRESS CURVE REPORT

PART II. PROGRESS CURVE REPORT

1. WBS ELEMENT CODE	3. UNITS/LOTS COMPLETED *(Specify)* ☐ UNIT TOTAL OR ☐ UNIT AVERAGE ☐ LOT TOTAL OR ☐ LOT AVERAGE
2. REPORTING ELEMENT	

	COMPLETED UNITS/LOTS A				WORK-IN-PROCESS (WIP)	TO COMPLETE
DATA ELEMENTS	**1**	**2**	**3**	**4**	**B**	**C**
1. MODEL AND SERIES						
2. FIRST UNIT OF LOT/WIP UNITS						
3. LAST UNIT OF LOT						
4. CONCURRENT UNITS/LOTS						
CHARACTERISTICS						
5.a						
5.b						
5.c						
PRIME CONTRACTOR						
6. DIRECT QUALITY CONTROL LABOR HOURS						
7. DIRECT MANUFACTURING LABOR HOURS						
8. TOTAL DIRECT LABOR HOURS						
9. DIRECT QUALITY CONTROL LABOR DOLLARS						
10. DIRECT MANUFACTURING LABOR DOLLARS						
11. TOTAL DIRECT LABOR DOLLARS						
12. RAW MATERIALS AND PURCHASED PARTS						
13. PURCHASED EQUIPMENT						
14. TOTAL DIRECT DOLLARS						
SUBCONTRACT/OUTSIDE PRODUCTS AND SERVICES						
15. DIRECT QUALITY CONTROL LABOR HOURS						
16. DIRECT MANUFACTURING LABOR HOURS						
17. TOTAL DIRECT LABOR HOURS						
18. DIRECT QUALITY CONTROL LABOR DOLLARS						
19. DIRECT MANUFACTURING LABOR DOLLARS						
20. TOTAL DIRECT LABOR DOLLARS						
21. RAW MATERIALS AND PURCHASED PARTS						
22. PURCHASED EQUIPMENT						
23. TOTAL DIRECT DOLLARS						
TOTAL PER UNIT/LOT						
24. DIRECT QUALITY CONTROL LABOR HOURS						
25. DIRECT MANUFACTURING LABOR HOURS						
26. TOTAL DIRECT LABOR HOURS						
27. DIRECT QUALITY CONTROL LABOR DOLLARS						
28. DIRECT MANUFACTURING LABOR DOLLARS						
29. TOTAL DIRECT DIRECT LABOR DOLLARS						
30. RAW MATERIALS AND PURCHASED PARTS						
31. PURCHASED EQUIPMENT						
32. TOTAL DIRECT DOLLARS						
33. % SUBCONTRACT OR OUTSIDE PRODUCTION AND SERVICES						

34. REMARKS

POINT OF CONTACT (POC) INFORMATION

35a. NAME *(Last, First, Middle Initial)*	35b. DEPARTMENT	35c. TELEPHONE NO. *(Include Area Code)*	
35d. E-MAIL ADDRESS	35e. FAX NO. *(Include Area Code)*	35f. SIGNATURE	35g. DATE SIGNED *(MM/DD/YY)*

DD FORM 1921-1, (BACK), OCT 2003

SECURITY CLASSIFICATION

Figure B-4: USA Functional Cost Hour and Progress Curve Report (DD Form 1921-1 Back).

Form Approved OMB No. 0704-0188

SECURITY CLASSIFICATION

COST DATA SUMMARY REPORT

1a. PROGRAM:

1b. APPROVED PLAN NUMBER:

2. DOLLARS IN

3. TYPE ACTION
- CONTRACT NO:
- LATEST AMENDMENT:
- RFP NO:
- PROGRAM ESTIMATE

4. APPROPRIATION
- RDT&E
- PROCUREMENT

5. REPORT AS OF *(MM/DD/YY)*

6 MULTI-YEAR CONTRACT
- YES
- NO

7. FY FUNDED:

8. CONTRACT TYPE

9. CONTRACT PRICE ESTIMATE

10. CONTRACT CEILING

11a CONTRACTOR TYPE
- PRIME/ASSOCIATE
- SUBCONTRACTOR

11b. NAME/ADDRESS

12. NAME OF CUSTOMER: *(Subcontractor Use Only)*

CONTRACT LINE ITEM A	REPORTING ELEMENTS B	WBS ELEMENT CODE C	TO DATE: NUMBER OF UNITS D	TO DATE: COSTS INCURRED NONRECURRING E	TO DATE: COSTS INCURRED RECURRING F	TO DATE: COSTS INCURRED TOTAL G	AT COMPLETION: NUMBER OF UNITS H	AT COMPLETION: COSTS INCURRED NONRECURRING I	AT COMPLETION: COSTS INCURRED RECURRING J	AT COMPLETION: COSTS INCURRED TOTAL K

13. REMARKS:

POINT OF CONTACT (POC) INFORMATION

14a. NAME *(Last, First, Middle Initial)*	14b. DEPARTMENT	14c. TELEPHONE NO. *(Include Area Code)*	
14d. E-MAIL ADDRESS	14e. FAX NO. *(Include Area Code)*	14f. SIGNATURE	14g. DATE SIGNED *(MM/DD/YY)*

DD FORM 1921, OCT 2003

Public reporting burden for this collection of information is estimated to average 33 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for information Operations and reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, D.C. 20503.

SECURITY CLASSIFICATION

Figure B-5: USA Cost Data Summary Report (DD Form 1921).

SECURITY CLASSIFICATION

Software Resources Data Report: Initial Government Report - Sample

Due 180 Days Before Contract Award as part of Cost Analysis Requirements Description (CARD)

Page 1: Report Context, Project Description and Size

1. Report Context	
1. System/Element Name (version/release):	2. Report As Of:
3. Authorizing Vehicle (MOU, contract/amendment, etc.):	4. Reporting Event: **CARD** Submission # ________ (Supersedes # _______, if applicable)
Comments on Part 1 responses:	

2. Product and Development Description	**Percent of Product Size**	**Upgrade or New?**
1. Primary Application Type:	2. %	4.
5. Secondary Application Type:	6. %	8.
9. Third Application Type:	10. %	12.
13. Fourth Application Type:	14. %	16.
17. Primary Language (expected or required):	18. %	
19. Secondary Language (expected or required):	20. %	
21. List COTS/GOTS Applications (expected or required):		
22. Peak staff (team size in FTE) expected to work on and charge to this project: __________		
Comments on Part 2 responses:		

3. Product Size Reporting	**Provide Estimates at CARD**
1. Number of anticipated Software Requirements, not including External Interface Requirements (unless noted in Data Dictionary)	
2. Number of anticipated External Interface Requirements (i.e., not under project control	
Code Size Measures for items 4 through 6. For each, indicate _S_ for physical SLOC (carriage returns); Snc for noncomment SLOC only; LS for logical statements; or provide abbreviation _________ and explain in associated Data Dictionary.	
4. Expected amount of New Code to be developed and delivered (Size in __________)	
5. Expected amount of Modified Code to be developed and delivered (Size in __________)	
6. Expected amount of Unmodified, Reused Code to be developed and delivered (Size in __________)	
Comments on Part 3 responses:	

DD Form 2630-1 **Page 1 of 2**

2/02/2004 **SECURITY CLASSIFICATION** ____________

Figure B-6: USA Software Resources Data Report – Initial Government Report (Page 1).

SECURITY CLASSIFICATION

Software Resources Data Report: Initial Government Report - Sample

Page 2: Project Resources, Schedule and Quality (Expected)

4. Resource and Schedule Reporting	**Provide Estimates at CARD**		
Counting from month 1 at contract award, provide Expected Start and End Month for each activity shown. Provide the Expected Total Labor Hours for each activity shown.	**Expected Start Month**	**Expected End Month**	**Expected Total Hours**
The following seven items should contain estimates that account for all direct hours required for the software development project (use item 7 for any direct hours not accounted for in items 1 through 6). Explain any contribution of indirect hours in the associated Data Dictionary.			
1. Software Requirements Analysis			
2. Software Architecture and Detailed Design			
3. Software Coding and Unit Testing			
4. Software Integration and System/Software Integration			
5. Software Qualification Testing			
6. Software Developmental Test and Evaluation			
7. All Other Direct Software Engineering Development Effort (Describe:____ ____) Estimate hours only:			
Comments on Part 4 responses:			

5. Product Quality Reporting (optional)	
One of the following items should be completed as a record of the expected reliability of the developed system.	
1a. Required Mean Time to Serious or Critical Defect (MTTD) at Delivery (provide specific definition in associated Data Dictionary):	__________ hours
1b. Alternatively, use analogy to provide some measure that compares the required reliability of this system with the nominal reliability for systems of this type. Use the associated Data Dictionary to provide details about the analogous systems and any definitions of reliability used in this response.	
Comments on Part 5 responses:	

Filename and Revision Date of Applicable *Software Resources Data Report Data Dictionary*:

Name of person to be Contacted	**Signature**	**Telephone Number**	**E-Mail**	**Date**

DD Form 2630-1 **Page 2 of 2**

2/02/2004 **SECURITY CLASSIFICATION** ____________

Figure B-7: Software Resources Data Report – Initial Government Report (Page 2).

SECURITY CLASSIFICATION

Software Resources Data Report: Initial Developer Report - Sample

Due 60 Days After Contract Award and 60 Days After Start of Any Release or Build

Page 1: Report Context, Project Description and Size

1. Report Context	
1. System/Element Name (version/release):	2. Report As Of:
3. Authorizing Vehicle (MOU, contract/amendment, etc.):	4. Reporting Event: **Project/Release Start** Submission # ________ (Supersedes # _______, if applicable)

Description of Planned Development Organization		
5. Name of Development Organization:	6. Certified CMM Level (or equivalent):	8. Lead Evaluator:
	7. Certification Date:	9. Affiliation:
10. Precedents (list up to five similar systems by the same organization or team):		
Comments on Part 1 responses:		

2. Product and Development Description	**Percent of Product Size**	**Planned Development Process**	**Upgrade or New?**
1. Primary Application Type:	2. %	3.	4.
5. Secondary Application Type:	6. %	7.	8.
9. Third Application Type:	10. %	11.	12.
13. Fourth Application Type:	14. %	15.	16.
17. Primary Language (planned):	18. %		
19. Secondary Language (planned):	20. %		
21. List COTS/GOTS Applications Planned:			
22. Peak staff (maximum team size in FTE) expected to work on and charge to this project: __________			
23. Percent personnel expected to be: Highly experienced in domain: ___% Nominally experienced: ___% Entry level, no experience: ___%			
Comments on Part 2 responses:			

3. Product Size Reporting	**Estimates at time of Contract Award**
1. Number of Software Requirements, not including External Interface Requirements (unless noted in associated Data Dictionary) expected to be satisfied by delivered software product	
2. Number of External Interface Requirements (i.e., not under project control) expected to be satisfied by delivered software product	
Code Size Measures for items 4 through 6. For each, indicate _S_ for physical SLOC (carriage returns); Snc for noncomment SLOC only; LS for logical statements; or provide abbreviation _________ and explain in associated Data Dictionary.	
4. Expected amount of New Code to be developed and delivered (Size in __________)	
5. Expected amount of Modified Code to be developed and delivered (Size in __________)	
6. Expected amount of Unmodified, Reused Code to be developed and delivered (Size in __________)	
Comments on Part 3 responses:	

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2/02/2004 SECURITY CLASSIFICATION

Figure B-8: Software Resources Data Report – Initial Developer Report (Page 1).

SECURITY CLASSIFICATION

Software Resources Data Report: Initial Developer Report - Sample			
Page 2: Project Resources and Schedule (Expected)			
4. Resource and Schedule Reporting	**Provide estimates at Contract Award**		
Counting from month 1 at contract award, provide Expected Start and End Month for each activity shown. Provide the Expected Total Labor Hours for each activity shown.	**Expected Start Month**	**Expected End Month**	**Expected Total Hours**
The following seven items should contain estimates that account for all direct hours required for the software development project (use item 7 for any direct hours not accounted for in items 1 through 6). Explain any contribution of indirect hours or uncompensated overtime in the associated Data Dictionary.			
1. Software Requirements Analysis			
2. Software Architecture and Detailed Design			
3. Software Coding and Unit Testing			
4. Software Integration and System/Software Integration			
5. Software Qualification Testing			
6. Software Developmental Test and Evaluation			
7. All Other Direct Software Engineering Development Effort (Describe:________________ ________________) Estimate hours only:			
Comments on Part 4 responses:			
5. Product Quality Reporting (optional)			
No Quality Reporting required at Contract Start.			
Filename and Revision Date of Applicable *Software Resources Data Report Data Dictionary*:			

Name of person to be Contacted	**Signature**	**Telephone Number**	**E-Mail**	**Date**

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2/02/2004 **SECURITY CLASSIFICATION**

Figure B-9: Software resources Data Report – Initial Developer Report (Page 2).

SECURITY CLASSIFICATION

Software Resources Data Report: Final Developer Report - Sample

Due 60 Days After Final Software Delivery and 60 Days After Delivery of Any Release or Build

Page 1: Report Context, Project Description and Size

1. Report Context			
1. System/Element Name (version/release):			2. Report As Of:
3. Authorizing Vehicle (MOU, contract/amendment, etc.):		4. Reporting Event: **Contract/Release End** Submission # ________ (Supersedes # _______, if applicable)	
Description of Actual Development Organization			
5. Development Organization:	6. Certified CMM Level (or equivalent):	8. Lead Evaluator:	
	7. Certification Date:	9. Affiliation:	
10. Precedents (list up to five similar systems by the same organization or team):			
Comments on Part 1 responses:			

2. Product and Development Description	**Percent of Product Size**	**Actual Development Process**	**Upgrade or New?**
1. Primary Application Type:	2. %	3.	4.
5. Secondary Application Type:	6. %	7.	8.
9. Third Application Type:	10. %	11.	12.
13. Fourth Application Type:	14. %	15.	16.
17. Primary Language Used:	18. %		
19. Secondary Language Used:	20. %		
21. List COTS/GOTS Applications Used:			
22. Peak staff (maximum team size in FTE) that worked on and charged to this project: __________			
23. Percent of personnel that was: Highly experienced in domain: ___% Nominally experienced: ___% Entry level, no experience: ___%			
Comments on Part 2 responses:			

3. Product Size Reporting	**Provide Actuals at Final Delivery**
1. Number of Software Requirements, not including External Interface Requirements (unless noted in associated Data Dictionary)	
2. Number of External Interface Requirements (i.e., not under project control)	
3. Amount of Requirements Volatility encountered during development (1=Very Low .. 5=Very High)	
Code Size Measures for items 4 through 6. For each, indicate _S_ for physical SLOC (carriage returns); Snc for noncomment SLOC only; LS for logical statements; or provide abbreviation _________ and explain in associated Data Dictionary.	
4. Amount of New Code developed and delivered (Size in __________)	
5. Amount of Modified Code developed and delivered (Size in __________)	
6. Amount of Unmodified, Reused Code developed and delivered (Size in __________)	
Comments on Part 3 responses:	

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2/02/2004 SECURITY CLASSIFICATION

Figure B-10: Software Resources Data Report – Final Developer Report (Page 1).

SECURITY CLASSIFICATION

Software Resources Data Report: Final Developer Report - Sample

Page 2: Project Resources, Schedule and Quality

4. Resource and Schedule Reporting	**Provide Actuals at Final Delivery**		
Counting from month 1 at contract award, provide Actual Start and End Month for each activity shown. Provide the Actual Total Labor Hours for each activity shown.	**Start Month**	**End Month**	**Total Hours**
The following seven items should account for all direct hours charged to the software development project (use item 7 for any direct hours not accounted for in items 1 through 6). Explain any contribution of indirect hours in the associated Data Dictionary.			
1. Software Requirements Analysis			
2. Software Architecture and Detailed Design			
3. Software Coding and Unit Testing			
4. Software Integration and System/Software Integration			
5. Software Qualification Testing			
6. Software Developmental Test and Evaluation			
7. All Other Direct Software Engineering Development Effort (Describe:____________ ____________) Report hours only:			
Comments on Part 4 responses:			

5. Product Quality Reporting (optional)	
One of the following items should be completed as a report on the reliability of the developed system.	
2a. Measured or computed Mean Time to Serious or Critical Defect (MTTD) at Delivery. Provide the specific definition of this measure in the associated Data Dictionary.	__________ hours
2b. Alternatively, use analogy to compare the observed or computed reliability of this system with the nominal reliability for similar systems. Use the associated Data Dictionary to provide details about the analogous systems and any definitions of reliability used in this response.	
Comments on Part 5 responses:	

Filename and Revision Date of Applicable ***Software Resources Data Report Data Dictionary*** **:**

Name of person to be Contacted	**Signature**	**Telephone Number**	**E-Mail**	**Date**

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Figure B-11: Software Resources Data Report – Final Developer Report (Page 2).

Annex C – EXAMPLE OF A TYPICAL LCC QUESTIONNAIRE

In order to conduct a comprehensive life cycle cost analysis, information from the supplier is required. This information can be gathered through formal approaches such as a Request for Information (RFI) or a more contractual Request for Quotation (RFQ) or Request for Proposal (RFP). If there is more than one potential supplier a tender competition may be conducted and an Invitation to Tender (ITT) will be issued. All the requests or ITT will contain some sort of life cycle cost questionnaire. Based on the experience of the participating nations in SAS-054, this annex gives an overview of elements that should be requested in a life cycle cost questionnaire.

There is no standard life cycle cost questionnaire that can be used for all acquisition projects. Any life cycle cost questionnaire should always be tailored for each specific case.

The questionnaire should first request information and data for all the ground rules and assumptions that have been taken into account in developing the cost estimates, preferably in the form of an MDAL (Master Data and Assumptions List) or CARD (Cost Analysis Requirements Document).

Other information should also be requested such as:

- Economic uncertainties;
- Demands for payment in advance;
- Different financial solutions; and
- Benefits with “dual use” (e.g. scale factors with more users).

At the very minimum, the total cost should be broken down into the following main cost areas (data that must be provided is shown *in italics*).

- Initial investment or acquisition costs, including development;
- Annual cost of operation and maintenance; and
- Cost of phasing out and disposing.

These main cost areas should, if possible, be broken down into the following cost elements:

1) Initial Investment or Acquisition Costs, including Development

- Procurement costs of the system
  - *Number and price per system*
  - *Number and price per subsystem*

- Initial logistic support costs
  - *Initial costs for training (operating and maintenance personnel)*
  - *Initial costs for spare parts*
  - *Initial costs of Test and Support Equipment*
  - *Initial cost of documentation*
  - *Initial costs computer hardware (e.g. interfaces) and software*
  - *Initial costs for infrastructure (facilities)*
  - *Initial costs consumables*

- Preparation costs

  Costs of testing prototypes

  Costs of installation of the system and adapting the system to the country specific circumstances

  Costs for testing and acceptance system

  Costs of transport and distribution of the system

- Other procurement costs

  e.g. costs of technical assistance (CETS or FSR)

2) Annual Cost of Operation

- Costs of operating personnel

  These costs will be not be provided by the supplier. However, in order to compare the number and type of operating personnel available and required, the supplier shall provide *the number and type of personnel required to operate the system.*

- Costs of periodic training operating personnel (both training new personnel and refreshment courses).
  - Costs of update service of operating documentation.
  - Costs of use infrastructure (facilities) for operating the system.
  - Costs of use of consumables.

  The costs may not be provided by the supplier. However, these costs can be calculated using the unit price and *the estimated use of fuel, oils, lubricants, ammunition and maintenance material***.**

3) Annual Cost of Maintenance

- *Costs of maintenance personnel at operational level.*

  These costs will be not be provided by the supplier. However, in order to compare the number and type of maintenance personnel available and required, the supplier shall provide the number and type (education level and type) of maintenance personnel required at operational level.

- *Costs of maintenance personnel at depot level.*

  These costs can be calculated by using the number of Man Maintenance Hours (MMH) at depot level for each type of personnel spent on maintenance on the system.

- *Costs of other personnel.*

  Costs of any other personnel not yet included.

- *Costs of periodic training maintenance personnel (both training new personnel and refreshment courses).*

- *Costs of spare parts consumption.*

- *Costs for outsourcing maintenance.*

- *Costs of use of Test and Support Equipment.*

- *Costs of update service of maintenance documentation.*
- *Costs of updating computer hardware and software.*
- *Costs for use of infrastructure required for maintenance.*
- *Package, handling, storage and transportation costs.*
- *Cost of recommended and mandatory modifications of the system.*

4) Cost of Phasing Out and Disposing

- *Possible retail price of the system or subsystems, after xx years of operation.*
- *Costs to dismantle or destruct the system or subsystems.*
- *Possible retail price of logistic support elements.*
- *Costs to destruct logistic support elements.*

For production contracts the following information should be specified for each cost element of the CBS in the price quotation:

- Labour cost – hours times hourly cost for each level of resources (e.g. Senior/Junior Engineer, Technician, etc.), including any external sub-contracted work;
- Material cost – if necessary, specifying costs for materials procured in country, in Euro countries or outside Euro countries – including a 2% surplus for scrap and also customs and insurance expenses where applicable; and
- Overheads – including material handling and other expenses (e.g. royalties, contract duties, production investment) where appropriate.

Annex D – LIFE CYCLE COSTING DEFINITIONS

Affordability: Can be considered as the degree to which the life cycle cost of an acquisition programme is *in consonance* with the long-range investment and force structure plans of national defence administrations. Affordability procedures establish the basis for fostering greater *programme stability* through the *assessment* of programme affordability and the *determination of affordability constraints*. In this context:

- *In consonance* means delivering systems that meet the customer's needs and budget.
- *Programme stability* means working towards sustainable opportunities.
- *Assessment* means creating a programme management strategy that guarantees programme viability.
- *Determination of affordability constraints* means bringing affordability to the foreground to avoid misconceptions in management and engineering which may ultimately lead to unaffordable design solutions.

Analogy: A technique used to estimate a cost based on historical data for an analogous system or subsystem. In this method, a currently fielded system, similar in design and operation to the proposed system, is used as a basis for the analogy. The cost of the proposed system is then estimated by adjusting the historical cost of the current system to account for differences (between the proposed and current systems). Such adjustments can be made through the use of factors (sometimes called scaling parameters) that represent differences in size, performance, technology, and/or complexity. Adjustment factors based on quantitative data are usually preferable to adjustment factors based on judgments from subject-matter experts.

Analysis of Alternatives (AoA): An analytical comparison of the operational effectiveness, suitability, and life-cycle cost of alternatives that satisfy established capability needs. Initially, the AoA process typically explores numerous conceptual solutions with the goal of identifying the most promising options, thereby guiding the concept refinement phase. Subsequently, the AoA is used to justify the rationale for formal initiation of the acquisition program. An AoA normally is not required for production decisions unless significant changes to threats, costs, or technology have occurred.

Cost Analysis Requirements Description: The CARD is used to formally describe Acquisition Category I and IA programs and systems in the United States DoD for purposes of preparing both the program office cost estimate (and the Component cost position, if applicable) and the OSD CAIG independent cost estimate. The CARD is provided in support of major milestone decision points (Milestone B, Milestone C, or the full-rate production decision review). In addition, for major AIS programs, the CARD is prepared whenever an economic analysis is required. The CARD is prepared by the program office and approved by the DoD Component Program Executive Officer (PEO). For joint programs, the CARD includes the common programme agreed to by all participating DoD Components as well as all unique program requirements of the participating DoD Components. DoD 5000.4-M, *DoD Cost Analysis Guidance and Procedures*, Chapter 1, provides further guidelines for the preparation of the CARD.

> Note that the CARD, ideally, provides both narratives and tabular data in sufficient detail for the programme to be costed. Naturally, the exact level of detail provided in the CARD will depend on the maturity of the programme. Programmes at Milestone B are less well-defined than programmes at Milestone C or at full-rate production. In cases where there are gaps or uncertainties in the various programme descriptions, these uncertainties are, again ideally, acknowledged as such in the CARD. Dealing with program uncertainty in the CARD greatly facilitates subsequent sensitivity or quantitative risk analyses in the life-cycle cost estimate.

Contractor Cost Data Reporting System: The primary means within the U.S. Department of Defense to systematically collect data on the development and production costs incurred by contractors in performing DoD acquisition program contracts. CCDR reports can provide for each contract a display of incurred costs to date and estimated incurred costs at completion by elements of the work breakdown structure, with nonrecurring costs and recurring costs separately identified. In addition, CCDR reports can display incurred costs to date and estimated incurred costs at completion by functional category (manufacturing, engineering, etc.). Each functional category is broken out by direct labour hours and major cost element (direct labour, direct material, and overhead). The CCDR manual (which provides report formats and definitions, specific report examples, and other related information) can be found at the Defense Cost and Resource Center (DCARC) web site. The DCARC is the OSD office responsible for administering the CCDR system.

Cost Element Structure (CES): A unit of costs to perform a task or to acquire an item. The cost estimated may be a single value or a range of values.

Cost Estimating Relationships (CERs): Equations that relate the cost of a weapon system or subsystem (or some other dependent variable) to one or more technical, physical, or performance characteristics of that system. CERs can range from simple rules of thumb derived as the average of a couple of data points to multi-variate regressions complete with a host of related statistics.

Cost Estimating (defined by SCEA, found in FAA Life Cycle Cost Estimating Handbook Sub-section 2.2): The art of approximating the probable cost or value of something based on information available at the time.

Cost model (taken from SAS-054 POW): A cost model is a set of mathematical and/or statistical relationships arranged in a systematic sequence to formulate a cost methodology in which outputs, namely cost estimates, are derived from inputs. These inputs comprise a series of equations, ground rules, assumptions, relationships, constants, and variables, which describe and define the situation or condition being studied. Cost models can vary from a simple one- formula model to an extremely complex model that involves hundreds or even thousands of calculations. A cost model is therefore an abstraction of reality, which can be the whole or part of a life cycle cost.

Data (taken from Joint publication 1-02 DoD Dictionary of Military and Associated Terms, 12/04/01, amend. 05/06/03 http://centre.chots.mod.uk/jel/pdfdocs/jel/diction/termdict.pdf): Representation of facts, concepts, or instructions in a formalised manner suitable for communication, interpretation, or processing by humans or by automatic means. Any representations such as characters or analog quantities to which meaning is, or might, be assigned.

Earned Value Management (EVM): A project management technique that objectively tracks physical accomplishment of work. EVM has the unique ability to combine measurements of technical performance (i.e. accomplishment of planned work), schedule performance (i.e. behind/ahead of schedule), and cost performance (i.e. under/over budget) within a single integrated methodology. EVM provides an early warning of performance problems while there is time for corrective action. In addition, EVM improves the definition of project scope, prevents scope creep, communicates objective progress to stakeholders, and keeps the project team focused on achieving progress.

> EVM emerged as a financial analysis specialty in United States Government programmes in the 1960s, but it has since become a significant branch of project management. Implementations of EVM can be scaled to fit projects of all sizes and complexity.

Economic Analysis: A systematic approach to the problem of choosing the best method of allocating scarce resources to achieve a given objective. A sound economic analysis recognises that there are alternative ways

to meet a given objective and that each alternative requires certain resources and produces certain results. To achieve a systematic evaluation, the economic analysis process employs the following two principles:

> Each feasible alternative for meeting an objective must be considered, and its life-cycle costs and benefits evaluated. All the costs and benefits are adjusted to "present value" by using discount factors to account for the time value of money. Both the size and timing of costs and benefits are important.

Engineering Estimates: With this technique, the system being costed is broken down into lower-level components (such as parts or assemblies), each of which is estimated separately for direct labour, direct material, and other costs. Engineering estimates for direct labour hours may be based on analyses of engineering drawings and contractor or industry-wide standards. Engineering estimates for direct material may be based on discrete raw material and purchase part requirements. The remaining elements of cost (such as quality control or various overhead charges) may be factored from the direct labour and material costs. The various discrete cost estimates are aggregated by simple algebraic equations (hence the common name "bottoms-up" estimate). The use of engineering estimates requires extensive knowledge of a system's (and its components') characteristics, and lots of detailed data.

Estimation Methods: Popular methods of estimating life cycle costs include analogy, engineering (bottoms-up), and parametric.

Inflation: A rise in the general level of prices, as measured against some baseline of purchasing power. In a U.S. DoD cost estimating environment, the following terms regarding inflation are commonly used:

Base Year: A point of reference that represents a fixed price level. In a weapon system acquisition context, this is often the fiscal year when a programme was initially funded.

Budget

Escalation: Application of the effects of inflation to a dollar amount. De-escalation is the reverse, or removing the effects of inflation from a dollar value.

Expenditures: A charge against available funds or the actual payment of funds evidenced by voucher, claim, or other document approved by competent authority.

Outlay Profiles: Indicates the rate at which dollars in each appropriation are expected to be expended based on historical experience.

Total Obligational Authority (TOA): The yearly value the defense programme, roughly equal to new budget authority plus any prior year balance still available for obligation.

Dollars

Base-Year Dollars: The money or prices expressed in terms of the purchasing power prevailing in a specified base year.

Constant-Year Dollars: Dollars expressed in their value at the time of any specified year, which may, but does not have to be, the base year. Also called "constant dollars."

Current-Year Dollars: Money or prices expressed in terms of values actually observed in the economy at any given time. That is, 2010 Current Year dollars would be the actual amount of dollars you'd have to pay in 2010 to purchase something of a given value in that year.

Then-Year Dollars: Constant or base-year dollars deflated or inflated through the use of indices to show total money needed to buy those goods and services at the time expenditures are actually made. Or, put another way, Total Obligational Authority (TOA) that includes a slice of inflation to cover escalation of expenditures over a multi-year period.

Indices

Raw: An annual compounding of escalation or inflation rates from a fixed point of reference, designated 100 or 1.0, and called the base year.

Weighted: A combination of raw escalation or inflation indices and outlay rates that indicates the amount of escalation occurring over the entire period of time that is required to expend TOA.

Learning and Experience Curves: The **learning curve effect** and the closely related **experience curve effect** express the relationship between experience and efficiency. As individuals and/or organizations get more experienced at a task, they usually become more efficient at them. Both concepts originate in the adage, "practice makes perfect," and both concepts are opposite to the popular misnomer that a "steep" learning curve means that something is hard to learn. In fact, a "steep" learning curve implies that something gets easier quickly.

The learning curve effect states that the more times a task has been performed, the less time will be required on each subsequent iteration. It was discovered by the 19th-century German psychologist Hermann Ebbinghaus. This relationship was probably first quantified in 1936 at Wright-Patterson Air Force Base in the United States, where it was determined that every time total aircraft production doubled, the required labour time decreased by 10 to 15 percent.

The experience curve effect is broader in scope than the learning curve effect encompassing far more than just labour time. It states that the more often a task is performed the lower will be the cost of doing it. The task can be the production of any good or service. Each time cumulative volume doubles, value added costs (including administration, marketing, distribution, and manufacturing) fall by a constant and predictable percentage.

Life Cycle (taken from Joint publication 1-02 DoD Dictionary of Military and Associated Terms, 12/04/01, amend. 05/06/03 http://centre.chots.mod.uk/jel/pdfdocs/jel/diction/termdict.pdf): The total phases through which an item passes from the time it is initially developed until the time it is either consumed in use or disposed of as being excess to all known materiel requirements.

Life Cycle Cost (LCC) (taken from RTO-TR-058 report): LCC consists of all direct costs plus indirect-variable costs associated with the procurement, O&S and disposal of the system. Indirect costs may include linked costs such as additional common support equipment, additional administrative personnel and non-linked costs such as new recruiters to recruit additional personnel. All indirect costs related to activities or resources that are not affected by the introduction of the system are not part of LCC.

Nature of Decision: LCC comprises the marginal costs (both direct and indirect) of introducing a new equipment or capability. LCC is used as a minimum for the analysis of alternatives, it does not include notional allocation of costs, whereas TOC and WLC might do so. LCC is used to compare options of alternatives, and often for economic analyses.

Military Requirements: (taken from Joint publication 1-02 DoD Dictionary of Military and Associated Terms, 12/04/01, amend. 05/06/03 http://centre.chots.mod.uk/jel/pdfdocs/jel/diction/termdict.pdf): An established need justifying the timely allocation of resources to achieve a capability to accomplish approved military objectives, missions, or tasks. Also called operational requirement.

Operations: (taken from JWP 0-01.1, Edition 6, http://www.chots.mod.uk/jointwar/): A military action or the carrying out of a strategic, tactical service, training, or administrative military mission: the process of carrying on combat, including movement, supply, attack, defence and manoeuvre needed to gain the objectives of any battle or campaign.

Parametric Estimating: This technique uses regression or other statistical methods to develop Cost Estimating Relationships (CERs). A CER is an equation used to estimate a given cost element using an

established relationship with one or more independent variables. The relationship may be mathematically simple (e.g. a ratio) or it may involve a complex equation (often derived from regression analysis of historical systems or subsystems). CERs should be current, applicable to the system or subsystem in question, and appropriate for the range of data being considered.

Product (taken from http://www.ams.mod.uk): The results of activities or processes. It includes (taken from RTO-TR-058 report) the products delivered to the user and the specific means required for developing and manufacturing these products. The products delivered to the user encompass the main system (aircraft, tank, etc.) and its support elements (spares, support equipment, facilities, documentation, etc.).

Project (taken from http://www.ams.mod.uk): The structure of authorities, resources and capabilities that supplies defined products and / or services within agreed time, cost and performance criteria.

Risk is exposure to loss. Or, in a weapon-system acquisition context, it is "a measure of the potential inability to achieve overall program objectives within defined cost, schedule, and technical constraints and has two components: (1) the **probability/likelihood** of failing to achieve a particular outcome, and (2) the **consequences/impacts** of failing to achieve that outcome".

Standardised Product: (taken from JWP 0-01.1, Edition 6, http://www.chots.mod.uk/jointwar/): A product that conforms to specifications resulting from the same or equivalent technical requirement. NATO standardised products are identified by a NATO code number.

Standardised Requirement (taken from JWP 0-01.1, Edition 6, http://www.chots.mod.uk/jointwar/): Within NATO, a broad statement identifying the levels of standardisation that should be achieved within specific areas of operations, materiel, administration and the related procedures".

Sensitivity Analysis: Attempts to demonstrate how the cost estimate would change if one or more assumptions change. Typically, for the high-cost elements, the analyst identifies the relevant cost-drivers, and then examines how costs vary with changes in the cost-driver values. For example, a sensitivity analysis might examine how maintenance manning varies with different assumptions about system reliability and maintainability values, or how system manufacturing labour and material costs vary with system weight growth. In good sensitivity analyses, the cost-drivers are not changed by arbitrary plus/minus percentages, but rather by a careful assessment of the underlying risks. Sensitivity analysis is useful for identifying critical estimating assumptions, but has limited utility in providing a comprehensive sense of overall uncertainty.

System (taken from http://www.ams.mod.uk): A human-made entity with a distinguishing and defined purpose that draws on integrated, constituent parts, each of which does not individually possess the required overall characteristics or purpose.

Task (taken from RTO-TR-058 report): Is the most elementary process or piece of work to be done, especially one done regularly to obtain an expected result and specified in terms of performance, cost and time. The performance of a task is entrusted to an identified actor and usually requires human, material and financial resources allocation.

Total Ownership Cost (TOC): Total ownership cost consists of the elements of a programme's life cycle cost, as well as other infrastructure or business processes costs not necessarily attributable to the programme. This may include items such as common support equipment, common facilities, personnel required for unit command, administration, supervision, operations planning and control, fuel and munitions handling.

Nature of Decision: TOC represents all costs associated with the ownership of a system except non-linked fixed costs that are related to the running of the organisation. TOC is used for budgeting

purposes, determining the use of services between systems, for optimisation purposes and for financial analysis.

Uncertainty: Is the indefiniteness or variance of an event. It captures the phenomenon of observations, either favourable or unfavourable, falling to the left and right of a mean or median value.

VAMOSC: The U.S.'s Visibility and Management of Operating and Support Costs (VAMOSC) system is the set of data and data management systems for the collection, display and cataloguing of historical O&S costs, related data, and associated factors that determine those costs, by individual defence programme. Each military department in the U.S. DoD is responsible for developing their own VAMOSC systems; hence, there is no single VAMOSC system, but rather several closely related but independent VAMOSC systems. VAMOSC data can be displayed in several different formats, including the CAIG standard cost element structure. Data can be obtained for entire systems, or at lower levels of detail. VAMOSC provides not only cost data, but related non-cost data (such as OPTEMPO or maintenance man-hours) as well. This type of data is useful for analogy estimates (between proposed systems and appropriate predecessor or reference systems) and for "bottoms-up" engineering estimates (for fielded systems or components, possibly adjusted for projected reliability and maintainability growth). VAMOSC data should always be carefully examined before use in a cost estimate. The data should be displayed over a period of a few years (not just a single year), and stratified by different sources (such as major command or base). This should be done so that abnormal outliers in the data can be identified, investigated, and resolved as necessary.

Whole Life Cost (WLC) (taken from RTO-TR-058 report): WLC consists of all elements that are part of TOC plus indirect, fixed, non-linked costs. These latter may include items such as family housing, medical services, ceremonial units, basic training, headquarters and staff, academies, recruiters. In WLC all costs or expenses that are made by the organisation are attributed to the systems or products they produce.

Nature of Decision: As WLC represents the total budget provision including such element as headquarters costs, it allows the visibility of the complete allocation of funds. WLC is used for a strategic view and high level studies.

Work Breakdown Structure (WBS): A technique for representing all the components, software, services and data contained in the project scope statement. It establishes a hierarchical structure or product oriented "family tree" of elements. It is used to organise, define and graphically display all the work items or work packages to be done to accomplish the project's objectives.

Annex E – PAPS MILESTONE DEFINITIONS

The following descriptions of the PAPS milestones have been drawn directly from AAP-20. See Chapter 3.2 for a description of the PAPS life cycle phases. Figure 3.1 gives an overview of the milestones and their relationship with the PAPS life cycle phases.

E.1 MISSION NEED DOCUMENT (MND)

A statement based on a mission analysis, identifying in broad outline a quantitative or qualitative operational deficiency that cannot be solved satisfactorily with existing or planned forces and/or equipment.

E.2 OUTLINE NATO STAFF TARGET (ONST)

A very broad outline of the function and desired performance of a new weapon or equipment, to satisfy a mission need, before the possibilities of achievement and the financial aspects have been examined. Contains operational characteristics, details of the threat, desired capability and a general indication of scope in particular and broad cost parameters whenever possible. Sufficient detail is given to enable a pre-feasibility study (or studies) to be carried out.

E.3 NATO STAFF TARGET (NST)

A broad outline of the function and desired performance of new equipment or weapon system(s), before the feasibility or method of meeting the requirement, or other implications have been fully assessed. Based upon the findings of any pre-feasibility study (studies) the NATO Staff Target lists, in greater detail, operational characteristics and certain technical specifications which are desired and which have been shown to be broadly feasible. It may also contain cost parameters when required. The NST is used as a basis for the Request for Proposals (RFP) from industry for a feasibility study of candidate system solutions.

E.4 NATO STAFF REQUIREMENT (NSR)

A detailed statement of the required design parameters and operational performance of the equipment or weapon system(s). This document represents the specification of the system upon which project definition is based.

E.5 NATO DESIGN AND DEVELOPMENT OBJECTIVE (NADDO)

An outline statement which covers the evaluation of design proposals in relation to the user requirement, the statement of agreed characteristics, and the design and technical requirement specifications. It includes as far as possible demonstrated achievement of stated requirements and objectives for the future, aimed at ensuring full system integration.

E.6 NATO PRODUCTION OBJECTIVE (NAPO)

An outline statement of the manufacturing processes, manpower and facilities required for production of the equipment, including an outline production programme based on cost plans, quality control requirements, and the stated production specification.

E.7 NATO IN-SERVICE GOALS (NISEG)

A statement of general utilisation intentions for equipment including reference to national or co-operative logistics and training arrangements.

E.8 NATIONAL DISENGAGEMENT INTENTION (NADI)

A statement of a decision to withdraw equipment from operational utilisation including forecast dates, quantities, and other relevant information such as age, condition of equipment, and availability of spare parts.

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's References	3. Further Reference	4. Security Classification of Document
	RTO-TR-SAS-054 AC/323(SAS-054)TP/51	ISBN 978-92-837-0072-2	UNCLASSIFIED/ UNLIMITED

5. Originator

Research and Technology Organisation
North Atlantic Treaty Organisation
BP 25, F-92201 Neuilly-sur-Seine Cedex, France

6. Title

Methods and Models for Life Cycle Costing

7. Presented at/Sponsored by

Final Report of Task Group SAS-054.

8. Author(s)/Editor(s)	9. Date
Multiple	June 2007

10. Author's/Editor's Address	11. Pages
Multiple	226

12. Distribution Statement

There are no restrictions on the distribution of this document. Information about the availability of this and other RTO unclassified publications is given on the back cover.

13. Keywords/Descriptors

Armed forces procurement	Economic life analysis	Logistics support analysis
Budgeting	Life (durability)	Maintainability
COO (Cost of Ownership)	Life cycle costs	Methodology
Cost analysis	Life cycles	Military planning
Cost comparison	Logistics planning	Models
Cost estimates	Logistics support	Service life

14. Abstract

This report is the product of the System Analysis and Studies (SAS) Task Group SAS-054 review of NATO and Partner nations' cost forecasting methods and models. The Task Group's core objectives were to understand NATO and Partner nations' methods and models for life cycle costing, and to promulgate best practice within the NATO Phased Armaments Programming System (NAPS). The SAS-054 report provides a comprehensive view on the application and use of life cycle costing from an early conceptual phase in the product life cycle through to the disposal phase. It provides illustrations on the types of life cycle cost studies that can be conducted and examples to demonstrate the benefits of such analysis. The treatment of uncertainty and risk within the context of developing the life cycle cost estimate is also explained within the report. The report concludes with a number of recommendations to improve the use and understanding of life cycle costing in the decision making process.

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